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Faculdade de Motricidade Humana

Atividade Neuromuscular no Swing do Golfe

Dissertação elaborada com vista à obtenção do Grau de Doutor no ramo de Motricidade Humana na especialidade de Comportamento Motor

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Resumo Geral

O objetivo desta tese foi estudar da atividade neuromuscular da técnica de *swing* da modalidade de golfe. Para concretizar o objetivo foram realizados cinco estudos: um estudo em que se efetuou uma revisão de literatura sobre a atividade neuromuscular do *swing* de golfe e quatro estudos laboratoriais que analisaram o *swing* de golfe nos músculos do membro superior, tronco e do membro inferior.

A revisão de literatura apresentou resultados dos estudos sobre eletromiografia (EMG) no *swing* de golfe, compreendendo uma discussão das metodologias e dos parâmetros de intensidade e tempo e salientando limitações e necessidades para o futuro.

Pela análise da participação muscular com recurso a EMG de superfície, verificámos que os músculos do membro superior dominante, tronco e membro inferior demonstraram maiores níveis de ativação durante as fases de *Forward Swing* e *Acceleration*. O nível de intensidade de cada um dos músculos estudados naqueles segmentos corporais foi quantificado relativamente ao EMG da contração voluntária máxima. A intensidade de ativação dos músculos do tronco não foi influenciada pela utilização de diferentes tipos de taco, ao contrário do que se verificou nos músculos do membro inferior. No membro inferior, foram encontradas diferenças nos níveis de ativação muscular entre os golfistas de baixo *handicap* (<5) e alto *handicap* (>22).

Palavras-Chave: Eletromiografia, golfista, *handicap*, padrão de ativação, fases do *swing*, tacos de golfe, intensidade, membro superior dominante, membro inferior, tronco.

Abstract

The main goal of this thesis was centred on the neuromuscular activity during the golf swing technique. To accomplish this objective five studies were performed: one literature review about the neuromuscular activity during the golf swing and four laboratory studies that analysed the trunk, upper limb and lower limb muscles during the golf swing.

The literature review showed results in the electromyographic (EMG) studies during the golf swing, comprehending a discussion on methodology and intensity and time, emphasising limitations and needs for the future.

Through the muscular analysis with surface EMG, we found that the dominant upper limb, trunk and lower limb muscles exhibited higher activation levels during the *Forward Swing* and *Acceleration* phases. The intensity levels of each muscle in those body segments were quantified with the maximal voluntary contraction. The intensity parameters of the trunk muscles are not influenced by the use of different clubs, and yet it was verified in lower limb muscles. Still in what the lower limb is concerned, differences were found in the muscular activation levels between the low *handicap* (<5) and high *handicap* golfers (>22).

Keywords: Electromyography, golfer, handicap, activity patterns, swing phases, golf clubs, intensity, dominant upper limb, lower limb, trunk.

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Capítulo 1 – Introdução

Enquadramento da tese

O golfe é um desporto acessível a indivíduos de todas as idades e níveis de condição física. É um desporto que oferece uma alternativa de prática de atividade física saudável e tem aumentado a sua popularidade, principalmente nos últimos quinze anos, em todo o mundo, e inclusive em Portugal. A grande atração deste jogo é particularmente visível na população de escalão etário superior devido ao aumento de tempo livre e por ser um desporto de baixo impacto com grande componente aeróbia. Por esse motivo o jogador médio tende a ser mais velho.[1]

No golfe a *performance* e a habilidade não são limitados pela idade mas dependem do tempo de prática e da exigência financeira. As características de um jogador de golfe são pouco conhecidas e apresentam fortes possibilidades de lesão por terem poucas ou deficitárias estruturas de exercícios, obrigarem à existência de propriedades específicas ao nível morfológico e funcional, ou as exigências mecânicas relacionadas com a natureza das atividades desportivas.[1]

O objetivo principal de um jogador de golfe quando realiza um *swing* é transmitir a potência necessária à bola para a aproximar o mais possível do buraco. O *swing* do golfe é a técnica predominante durante o jogo, e é responsável pela maioria das lesões.[2] Devido ao aumento de participação, alguns relatórios indicam que o número de lesões relacionadas com o golfe também está a aumentar. Os estudos mais recentes indicam que até 70% dos jogadores de golfe têm experiência de lesões como resultado de praticarem a um nível insatisfatório num período reduzido de tempo.[3] No entanto, ainda não foram estabelecidas relações entre os riscos da prática do golfe e os benefícios para a saúde, o que leva a alguma controvérsia.[4] De forma a esclarecer os mecanismos de lesões nos jogadores médios e melhorar a qualidade de intervenção e de condição física, é necessário interpretar a epidemiologia existente à luz de natureza cinética, cinemática e neuromuscular relativa aos jogadores de golfe de nível médio.

Para realizar o movimento do *swing* o Sistema Nervoso Central (SNC) do golfista tem que controlar um grande conjunto de músculos que atuam nos diferentes segmentos corporais, de forma a produzir ativações musculares numa determinada sequência e duração e com intensidades ajustadas ao movimento pretendido. A eletromiografia (EMG) de superfície é um método de estudo que permite registar a atividade elétrica gerada pelos músculos durante a contração, através de elétrodos bipolares colocados na pele. Trata-se de uma ferramenta útil para conseguir informação sobre os parâmetros de intensidade e estrutura temporal dos padrões neuromusculares gerados pelo SNC.[5] A informação assim obtida é útil para a melhor compreensão dos fenómenos associados à prevenção de lesões, à gestão da condição muscular, à melhoria dos processos de controlo motor e aprendizagem no golfe.

A última revisão de literatura sobre EMG no golfe foi realizada por McHardy & Pollard[6] que pesquisaram na *Medline* estudos realizados entre 1965 e 2005. Nesta revisão os investigadores encontraram 12 estudos: dois eles eram revisões bibliográficas,[7,8] sete foram produzidos pelo mesmo grupo de investigadores[9-15] e três foram publicados no livro do Congresso Científico Mundial de Golf.[16-18]

Os músculos analisados na realização do swing no golfe incluíam o ombro e os músculos da cintura escapular,[9-11,13] os músculos abdominais e os extensores do tronco.[12,15,19] Só dois estudos[20,21] foram realizados nos grupos musculares que atuam nas regiões distais do membro superior como o cotovelo e o punho, apesar de a literatura referir que, juntamente com a região lombar, são as articulações que detêm maior prevalência de lesões.[2,4,22-26] Apenas um estudo[14] foi conduzido com análise de EMG nos membros inferiores através da avaliação dos quatro músculos que atuam nas articulações da coxa e joelho.

Não foi encontrado nenhum estudo sobre a influência do uso de diferentes tacos de golfe nos padrões neuromusculares durante o swing. Contudo, Egret et al.[26] analisaram a influência de três tacos de golfe diferentes (*driver*, ferro-5 e *pitching-wedge*) nos padrões cinemáticos do swing realizados por jogadores de golfe de alto nível (*handicap* entre 0 e 3). Apesar de não encontrarem diferenças na estrutura temporal total do swing quando realizado com diferentes tacos, registaram-se diferenças cinemáticas.

A maior parte dos estudos de EMG existentes foram realizados em jogadores de *handicap* baixo,[9-15] no entanto é necessário investigar os padrões neuromusculares do jogador médio que constitui a maior parte dos praticantes e com grande incidência de lesões.[4]

Objetivos

Desde que o movimento do swing do golfe é conhecido, algumas mudanças têm ocorrido na sua execução e *performance*. O padrão de movimento tem-se alterado, mas poucos estudos[9-12,19] têm contribuído para o desenvolvimento de novas perspetivas de análise através da atividade eletromiográfica do músculo.

É importante realizar estudos com jogadores de golfe de nível mais baixo, porque eles representam a maioria da população que joga golfe, e também porque permitem caracterizar os seus padrões neuromusculares durante o *swing*, especialmente no membro inferior, segmento tão pouco estudado. Por outro lado, a influência do uso de diferentes tacos nos padrões neuromusculares durante o *swing* não está bem descrito, mas diferenças foram encontradas na cinemática e na velocidade da cabeça do taco.[16,28,29] Nesse caso, é de admitir a possibilidade de diferentes padrões de atividade muscular poderem estar presentes quando o *swing* é executado com diferentes tipos de taco, levando a distintos constrangimentos na execução técnica e, também, a um risco diferenciado de lesões músculo-esqueléticas.

Assim, o objetivo geral desta tese foi realizar, com base em registos EMG de superfície, a caracterização da participação neuromuscular durante *swing* de golfe executado com diferentes tipos de taco, com enfoque especial nos jogadores de *handicap* de nível médio. Para esse fim estabeleceram-se os seguintes objetivos específicos:

- Revisão sistemática de literatura sobre a análise EMG do *swing*;
- Caracterização EMG dos músculos do tronco no *swing* do jogador de nível médio e análise da influência da utilização de diferentes tipos de taco;
- Caracterização EMG dos músculos do membro inferior no *swing* do jogador de nível médio e análise da influência da utilização de diferentes tipos de taco;
- Comparação dos padrões EMG dos músculos do membro inferior no *swing* em golfistas de *handicap* distinto (reduzido e elevado).

Estrutura da tese

A presente tese desenrola-se em nove capítulos que pretendem responder aos objetivos traçados. Uma análise sumária da sua estrutura é apresentada na Tabela 1.

O capítulo 1 inclui o enquadramento geral do tema, descrevem-se os objetivos e apresenta-se a respetiva estrutura.

O capítulo 2 foca a metodologia comum dos diversos estudos experimentais ocorridos em laboratório.

O capítulo 3 versa a revisão de literatura sobre os estudos centrados na análise eletromiográfica do *swing* do golfe. Pretendemos fazer uma atualização de todo o conhecimento disponível sobre a caraterização da participação neuromuscular no *swing* com base na quantificação das variáveis eletromiográficas, bem como uma análise crítica das limitações metodológicas evidenciadas nesses estudos. Esse capítulo foi fundamental para uma definição mais concreta dos estudos posteriormente desenvolvidos.

O capítulo 4 inclui um pré-estudo sobre a caraterização da participação muscular do membro superior dominante no *swing* em jogadores de baixo *handicap.* Esse pré-estudo serviu também para o desenvolvimento e testagem de rotinas de processamento e análise do sinal EMG a serem usadas nos capítulos posteriores na análise do *swing* de golfe.

O capítulo 5 realiza a caracterização EMG dos músculos do tronco no jogador de nível médio, bem como a análise do efeito da utilização de dois tipos de taco.

Os capítulos 6 e 7 centram-se na análise EMG da musculatura do membro inferior no *swing*. O capítulo 6 caracteriza os padrões neuromusculares em jogadores de nível médio e as alterações induzidas por três tipos de taco, enquanto o capítulo 7 compara os padrões de ativação entre jogadores com baixo e elevado *handicap*.

O capítulo 4 está redigido em Inglês por ter sido um estudo experimental e de preparação para publicações futuras. Os capítulos 3, 5, 6 e 7 são apresentados em Inglês e com formatação diferenciada por corresponderem a artigos submetidos a revistas internacionais com arbitragem científica.

O capítulo 8 foca-se na discussão geral dos resultados, através de uma visão global do *swing* do golfe, tendo como base os estudos nos capítulos anteriores, as suas limitações e perspectivas para linhas de investigação para o futuro.

O capítulo 9 consubstanciar-se nas conclusões, sintetizado o conhecimento produzido nos estudos elaborados nesta tese.

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Capítulo 2 – Metodologia

É objetivo deste capítulo descrever, de forma geral, os aspetos essenciais da metodologia utilizada nos estudos experimentais realizados nos capítulos 4 a 7.

Procedimentos Gerais

Todos os participantes foram informados dos objetivos do estudo em que se integraram e das etapas de recolha de dados e, posteriormente, preencheram um questionário sobre as suas características e experiência no golfe. A pele foi preparada previamente à colocação dos elétrodos. Seguidamente, realizaram um aquecimento de aproximadamente cinco minutos para uma melhor adaptação à tarefa. As recolhas só se iniciaram quando os participantes se consideraram preparados para as realizar.

Os participantes foram orientados para realizar o *swing* de acordo com as distâncias normalmente conseguidas com o tipo de taco com que estavam a executar, de forma a que a execução fosse o mais real possível. Cada sujeito realizou quatro (Estudo II), cinco (Estudo III) ou oito (Estudo IV e V) execuções do *swing* por cada condição (velocidade do swing – Estudo II; diferentes tacos – Estudos III e IV). O *swing* foi executado sobre um tapete de relva artificial com características de alta absorção de choque.

Captura, processamento e análise do sinal de vídeo

A captura, processamento e análise de vídeo foram utilizados para se proceder à divisão do *swing* em fases. Foram utilizadas três (Estudo III), quatro (Estudo II) ou cinco (Estudo IV e V) câmaras Basler A602fc (Basler Vision Technologies, Ahrensburg, Alemanha) de alta velocidade a 300Hz (Estudo II) ou 100Hz (Estudo III, IV e V). Uma outra câmara, Casio EX-FH20 (Casio, Tóquio, Japão) a 1000Hz, foi colocada perto da bola para determinar o instante de impacto.

Para se realizar uma análise a três dimensões foi utilizado o sistema SIMI Motion (SIMI Reality Motion Systems GmbH, Unterschleissheim, Alemanha). Foram colocadas duas marcas refletoras nas extremidades do corpo do taco, tal como foi utilizado por

Horton et al.[1], para identificar as cinco fases do swing (Estudos III, IV e V), tal como é mais frequentemente descrito na literatura[2-7]:

(1) *Backswing* – desde a posição inicial até ao topo do swing;

(2) *Forward Swing* – desde o topo do swing até o taco ficar horizontalmente posicionado (fase descendente do taco – fase inicial do *Downswing*);

(3) *Acceleration* – desde a posição horizontal do taco até ao impacto (fase descendente do taco – fase final do *Downswing*);

(4) *Early Follow-Through* – desde o impacto até o taco ficar horizontalmente posicionado (fase ascendente do taco);

(5) *Late Follow-Through* – desde a posição horizontal do taco até ao final do swing.

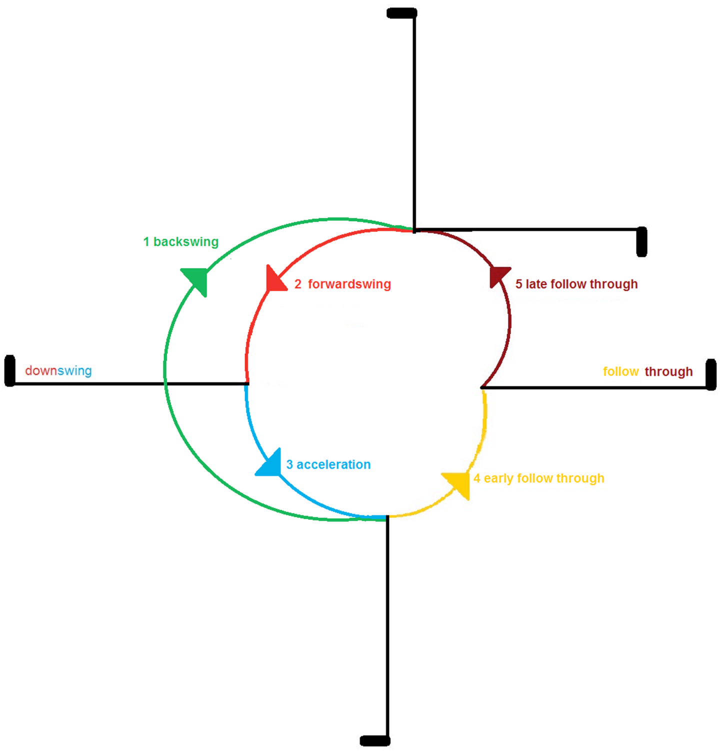

Figura 1 – Fases do swing do golfe

No estudo II foi feita uma divisão em apenas três fases (*Backswing*, *Downswing* e *Follow-Through*), tendo sido também utilizado um acelerómetro Biopac (Biopac Systems Inc., USA).

Captura, processamento e análise do sinal de EMG

A preparação da pele visou reduzir a impedância desta com o elétrodo durante as recolhas EMG. Assim, na zona de contacto entre a pele e o elétrodo foi removido o pelo, realizada a abrasão e limpa com álcool. Os elétrodos foram colocados em alinhamento com as fibras musculares na região mais saliente do ventre muscular, com uma distância centro-a-centro de 20mm (Estudo II e III), 22mm (Estudo IV e V), utilizando as referências descritas na literatura[8]. O elétrodo terra foi colocado no manúbrio do esterno[1].

Os sinais eletromiográficos foram recolhidos com elétrodos ativos (PLUX, Lisboa, Portugal - Estudo II e III) (AMBU, Ballerup, Dinamarca – Estudo IV e V) e um equipamento de telemetria bioPLUX® research 2010 (PLUX, Lisboa, Portugal) e ligação por Bluetooth (Estudo IV e V). Os sensores amplificaram os sinais de EMG com uma banda de passagem de 10-500hz, razão de rejeição de modo comum de 110 dB e impedância de entrada maior do que 100 MΩ. Todos os sinais foram digitalizados a 1000Hz, posteriormente filtrados digitalmente (10-490hz), retificados, suavizados com um filtro digital de passo-baixo (12Hz, 4ª ordem Butterworth) e normalizados usando como referência o pico de 1 segundo do máximo de EMG (EMG_{max}) recolhido durante a Contração Voluntária Máxima (CVM).

Foram realizadas duas contrações voluntárias máximas de 3 a 4 segundos para se proceder posteriormente à normalização dos sinais EMG. Todos os participantes foram encorajados verbalmente durante os exercícios de CVM e foram permitidos dois minutos de pausa entre repetições para evitar fadiga. Os procedimentos de normalização utilizados são consistentes com os utilizados por Hermens et al.[8], Konrad[9], e McGill[10].

O processamento de sinal de EMG foi realizado com o auxílio de uma rotina de MATLAB® V.R2010a (Estudo II e III), V.R2013a (Estudo IV e V) (The Mathworks Inc., Natick Massachusetts, EUA). A qualidade do sinal em bruto foi previamente garantida através da inspeção visual realizada por investigadores experientes.

O valor médio do sinal de EMG durante cada uma das fases do swing foi calculado para cada repetição, condição e participante.

Na tabela 1 encontram-se resumidos os principais aspetos metodológicos (objetivo, amostra, músculos e variáveis estudadas) envolvidos em cada um dos estudos.

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Tabela 1: Quadro sinóptico da estrutura da presente tese.

	Capítulo 3	**Capítulo 4**	**Capítulo 5**	**Capítulo 6**	**Capítulo 7**
Objetivo	Revisão sistemática de literatura sobre análise EMG do *swing*	Caracterização EMG dos músculos do membro superior dominante no *swing* Desenvolvimento e testagem de Matlab para processamento e análise do sinal EMG	Caracterização EMG dos músculos do tronco no *swing* Comparação de diferentes tipos de taco	Caracterização EMG dos músculos do membro inferior no *swing* Comparação de diferentes tipos de taco	Comparação EMG dos músculos do membro inferior no *swing* entre golfistas de baixo e elevado handicap
Amostra	n = 19	n = 3	n = 8	n = 14	n = 10 (5 em cada grupo de handicap)
Músculos	Todo o corpo	• Deltoide (três porções) • Grande Peitoral • Grande Dorsal • Infraespinhoso • Vasto lateral do TB • Longa porção do TB • Bicípite Braquial • Longo Supinador • Flexores do punho • Extensores do punho	Bilateral: • Grande Oblíquo Abdómen • Recto do Abdómen • Erector da coluna • Grande Glúteo	Bilateral: • Tibial Anterior • Longo Peroneal • Gêmeo Lateral • Gêmeo Medial • Recto Femoral do QC • Vasto Externo do QC • Vasto Interno do QC • Grande Glúteo • Semitendinoso • Bicípite Femoral	Bilateral: • Tibial Anterior • Longo Peroneal • Gémeo Lateral • Gémeo Medial • Recto Femoral do QC • Vasto Externo do QC • Vasto Interno do QC • Grande Glúteo • Semitendinoso • Bicípite Femoral
Variáveis independentes		• Fases do swing • Músculos	• Fases do swing • Músculos • Tacos – Ferro 4 e pitching wedge	• Fases do swing • Músculos • Tacos – Ferro 7, Ferro 4 e pitching wedge	• Handicap: Handicap baixo (<5) e handicap elevado (>20)
Variáveis dependentes	% EMG CVM (ou MMT) de cada músculo em cada fase Onset EMG (ms)	% EMG CVM de cada músculo em cada fase onset (ms)	% EMG CVM de cada músculo em cada fase	% EMG CVM de cada músculo em cada fase	% EMG CVM de cada músculo em cada fase Duração de cada fase (ms)
Publicação	*Artigo*		*Poster e Artigo*	*Artigo*	*Artigo*

Legenda: BS - Backswing, FS - Forward Swing, ACC - Acceleration, EFT - Early Follow-Through, LFT - Late Follow-Through, CVM – Contração Voluntária Máxima; TB – Tricípite Braquial; QC – Quadricípite Crural

Capítulo 3

Estudo I

Variáveis eletromiográficas durante o swing do golfe: Uma revisão de literatura

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Review

Electromyography variables during the golf swing: A literature review

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ABSTRACT

The aim of the study was to review systematically the literature available on electromyographic (EMG) variables of the golf swing. From the 19 studies found, a high variety of EMG methodologies were reported. With respect to EMG intensity, the right erector spinae seems to be highly activated, especially during the acceleration phase, whereas the oblique abdominal muscles showed moderate to low levels of activation. The pectoralis major, subscapularis and latissimus dorsi muscles of both sides showed their peak activity during the acceleration phase. High muscle activity was found in the forearm muscles, especially in the wrist flexor muscles demonstrating activity levels above the maximal voluntary contraction. In the lower limb higher muscle activity of the trail side was found. There is no consensus on the influence of the golf club used on the neuromuscular patterns described. Furthermore, there is a lack of studies on average golf players, since most studies were executed on professional or low handicap golfers.

Further EMG studies are needed, especially on lower limb muscles, to describe golf swing muscle activation patterns and to evaluate timing parameters to characterize neuromuscular patterns responsible for an efficient movement with lowest risk for injury.

Contents

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1. Introduction

Golf is a sport accessible to all ages and levels of physical condition. It offers an healthy alternative physical activity and has become increasingly popular all over the world. Nowadays, the “older” population has more leisure time available and since golf is considered a low impact sport with a general aerobic component, the “average” player tend to be older in age. Although golf players’ characteristics are poorly studied, the sport is assumed to present some injury risks (McHardy et al., 2006), either through badly structured (or lack of) exercise programs and practice, specific morphological and functional properties of the participants, or through the nature of the mechanical demands of the activity. Due to increased participation, golf-related injuries are increasing, also. Cabri et al. (2009) indicated that golf players experienced injuries, resulting from overuse or from traumatic cause. However, health benefits and golf practice-related risks have not been fully explored. Furthermore, controversy still exists in the literature (Cabri et al., 2009).

The golf swing is an essential movement in the game and is considered to be responsible for the majority of golf-related injuries (Gosheger et al., 2003). In order to elucidate injury mechanisms in “average” golfers with different practice levels and to improve the quality and specificity of the golfers’ physical conditioning, neuromuscular information about the golf swing is needed to provide a correct interpretation of the available epidemiological record (McHardy and Pollard, 2005a).

Therefore, we aimed in this paper to review the available literature concerning its behavior during the golf swing through electromyography (EMG). EMG is the measurement of the electrical activity generated in the muscle and is a useful tool to get information about the intensity and time structure of neuromuscular impulses received in the muscle from the central nervous system (Basmajian and De Luca, 1985). We were particularly interested in (1) the characteristics of the subjects and swings studied, (2) to critically analyse the EMG methods used, and (3) to give an overview on muscle recruitment during the golf swing based on the recent literature available.

2. Methods

A systematic search of the existing literature was conducted using the combined keywords “golf” and “swing” on studies published between 1965 and 2011, in the electronic databases B-On, PubMed, Scopus, Google Scholar and ISI Web of Science. Then a refined search was made adding the keyword “electromyography” (EMG) on the first retrieved data. The inclusion criteria were: (1) containing EMG data on golf swing phases; (2) amateurs and/or professional golfers of all ages, all handicaps and/or a population with or without injuries; and (3) the articles written in English, French and Portuguese. The exclusion criteria were: (1) papers with no EMG data; (2) no swing phases description, and (3) publications in languages other than those used in the inclusion criteria.

3. Results

3.1. Literature search results

The electronic databases retrieved 5219 articles that fitted the criteria words: “golf” and “swing”. A refined search was then made to fit the criteria on EMG, retrieving 154 articles. Using reference manager software (Reference Manager V12, Thompson Reuters, USA) all duplicates were eliminated, which revealed 73 references for screening. Fifty-four articles were rejected because of lack of relevance to the criteria, and 19 articles went through further analysis (Fig. 1).

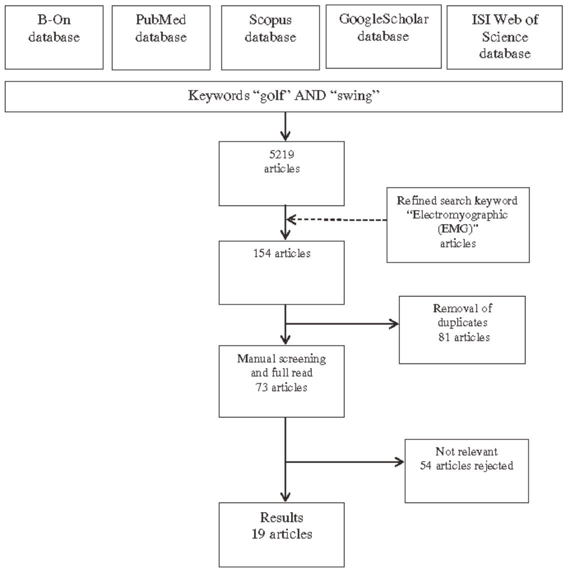

Fig. 1. Flow chart of methodology used for the article search.

3.2. The golf swing: movement phases

Most of the studies (Jobe et al., 1989; Pink et al., 1990, 1993; Kao et al., 1995; Bechler et al., 1995; Watkins et al., 1996; Farber et al., 2009) generally divided the golf swing into five phases using video analysis: (1) the backswing – from address to top of swing; (2) the forward swing – from top of swing to horizontal positioning of the golf club (early part of downswing); (3) the acceleration phase – from horizontal club position to ball impact (late part of downswing); (4) the early follow-through – from impact to a horizontal club positioning and; (5) the late follow-through – from horizontal club position to completion of the swing. Glazebrook et al. (1994) divided the golf swing into four phases: (1) address phase – preparation to swing (duration of 0.1 s); (2) the swing phase – from takeaway to beginning of contact phase; (3) contact phase – from the burst of common forearm flexor muscle activity to ball strike; (4) post contact phase – a 0.1 s period after ball strike. To Kao et al. (1995) the golf swing takeaway phase occurs from the address until the club is horizontal and the backswing phase from that point to the backswing top.

Although the small differences reported, we analyzed the retrieved data with respect to the most-used swing phases: (1) backswing; (2) downswing; (3) acceleration; (4) early follow-through; and (5) late follow-through (Fig. 2).

3.3. The golf swing: EMG data

The retrieved studies focussed mainly on four different body parts: trunk, shoulder, forearm and lower limb.

From the 19 retrieved articles, six analyzed the trunk (Pink et al., 1993; Watkins et al., 1996; Horton et al., 2001; Bulbulian et al., 2001; Cole and Grimshaw, 2008a,b), four studied the shoulder (Jobe et al., 1986, 1989; Pink et al., 1990; Kao et al., 1995), two the forearm (Glazebrook et al., 1994; Farber et al., 2009), one the lower limb muscles (Bechler et al., 1995). Six papers were

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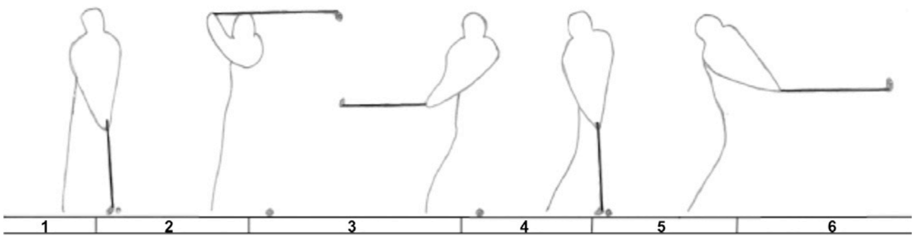

Fig. 2. Golf swing phases.

Table 1
Summary of subject data in studies performed in trunk muscles during the golf swing.

Author Year	n	Gender	Handicap	Age	Handed	Club	Special pop.
Pink et al. (1993)	23	Males	<5 (professional)	35 [25–56]	Right	–	–
Watkins et al. (1996)	13	Males	<5 (professional)	–	Right	–	–
Cole and Grimshaw (2008a,b)	30	Males	[0–12]	33, 25 ± 14, 54	Right	Own driver to a 320 m flag	8 AC
			[0–12]	37, 50 ± 14, 56			8 LBP
			[13–29]	52, 40 ± 10,93			10 AC
			[13–29]	63 ± 9, 76			4 LBP
Cole and Grimshaw (2008a,b)	27	Males	[2.07–18.93] [6.26–14.54]	46 ± 17, 85	Right	Own driver to a 320 m flag	12 LBP 15 NLBP
Bulbulian et al. (2001)	7	6 Males 1 Female	[5–29] Non professionals	25, 5 ± 3, 0	Right	7-Iron driver	–
Horton et al. (2001)	25	18 Males	<5 Professionals	29, 4 ± 2, 0	–	Driver	AC
		7 Males	Elite amateurs	36, 1 ± 2, 7			CLBP

AC – asymptomatic control; CLBP – chronic low back pain; LBP – low back pain; NLBP – no low back pain.

literature reviews of which three were on EMG analysis: one a general review on EMG and the golf swing (McHardy and Pollard, 2005a). Two were reviews dealing with EMG patterns of the upper limb (Escamilla and Andrews, 2009) and shoulder (Moynes et al., 1986). The other three literature reviews dealt with golf injuries but also mentioned EMG studies during the different swing phases (Kim et al., 2004; McHardy and Pollard, 2005b; Cabri et al., 2009).

Except for one study (Jobe et al., 1986), all studies mentioned investigated low handicap (<5) or professional players. Some papers compared subjects in special groups mainly related to low back pain (Horton et al., 2001; Cole and Grimshaw, 2008a,b) and medial epicondylitis (Glazebrook et al., 1994). Jobe et al. (1989) and Pink et al. (1990) analyzed differences between men and women in both the lead (left side for right handed golfers) and trail arm, whereas the other studies only used male participants. Only Kao et al. (1995) reported a left-handed subject. Subjects' characteristics from trunk, shoulder, forearm and lower limb are presented in Tables 1–4, respectively.

Table 2
Summary of subject data in studies performed in shoulder muscles during the golf swing.

Author Year	n	Gender	Handicap	Age	Handed
Jobe et al. (1989)	13	6 Males	Professionals	35 [30–42]	Right
		7 Females		32 [22–44]	
Kao et al. (1995)	15	Males	<5	36 [25–55]	14 Right 1 Left
Pink et al. (1990)	13	6 Males	Professionals	35 [30–42]	Right
		7 Females		32 [22–44]	
Jobe et al. (1986)	7	Males	Professionals	36	Right

3.4. Electromyography methodology

Tables 4–7 summarizes the main features of the EMG methods used in the different studies.

Seven studies used surface electrodes (Pink et al., 1993; Glazebrook et al., 1994; Watkins et al., 1996; Horton et al., 2001; Bulbulian et al., 2001; Cole and Grimshaw, 2008a,b) and other seven used fire wire electrodes (Jobe et al., 1986, 1989; Pink et al., 1990; Kao et al., 1995; Bechler et al., 1995; Farber et al., 2009).

All articles that recorded EMG using fire wire method specified the placement of the electrodes as well as the insertion method (Basmajian technique). In the surface method only some articles (Glazebrook et al., 1994; Horton et al., 2001; Cole and Grimshaw, 2008a,b) explained the electrodes placement.

Table 3
Summary of subject data in studies performed in forearm muscles during the golf swing.

Author Year	n	Gender	Handicap	Age	Handed
Farber et al. (2009)	n = 10 Professional	Males	⩽4	40, 3 [29–60]	Right
	n = 10 Amateurs		[10–20]	41, 1 [29–57]	
Glazebrook et al. (1994)	n = 8 Symptomatic	Males	[1–7]	29	–
			[9–19]	40, 5	
	n = 8 Asymptomatic		[1–7]	46	
			[9–19]	43, 7	

Table 4
The lower limb study by subject and electromyographic analysis.

Author Year	n	Gender	Handicap	Age	Handed	EMG	Muscles	Normalization
Bechler et al. (1995)	16	13 Males 3 Females	<5	36 [27–59]	Right	Single needle	UGM, LGM, GMED, ADM, BF, SM, VL	MMT Peak 1 s EMG signal
Watkins et al. (1996)	13	Males	Professional	–	Right	Surface	GM	MMT Peak 1 s EMG signal

UGM – upper gluteus maximus; LGM – lower gluteus maximus; GMED – gluteus medius; ADM – adductor magnus; BF – biceps femoris (long head); SM – semimembranosus; VL – vastus lateralis; GM – gluteus maximus; MMT – manual muscle test.

Table 5
Summary of electromyographic methods used in studies performed in trunk muscles during the golf swing.

Author Year	EMG	Muscle	Normalization	Onset	Offset	Obs.
Pink et al. (1993)	Surface	OA, ES	MMT Peak 1 EMG signal	–	–	–
Watkins et al. (1996)	Surface	OA, ES, RA	MMT Peak 1 EMG signal	–	–	–
Cole and Grimshaw (2008a,b)	Surface	ES, EO	Submaximal voluntary contraction	–	–	SF-MPQ
Cole and Grimshaw (2008a,b)	Surface	RA, EO, IO (bilaterally)	–	1SD over a mean 50 ms window	1SD over a mean 50 ms window	SF-MPQ
Bulbulian et al. (2001)	Surface	ES, EO (bilaterally)	–	–	–	1 – Full recoil backswing; 2 – a shorter and stressed modified backswing
Horton et al. (2001)	Surface	RA, EO, IO	Submaximal isometric contraction	–	–	PAR-Q; SF-MPQ

OA – oblique abdominal; ES – erector spinae; RA – rectus abdominis; EO – external oblique; IO – internal oblique; MMT – manual muscle test; SF-MPQ – short-form McGill pain questionnaire; PAR-Q – physical activity readiness questionnaire.

Table 6
Summary of electromyographic methods used in studies performed in shoulder muscles during the golf swing.

Author Year	EMG	Muscle	Normalization
Jobe et al. (1989)	Wire	AD, MD, PD, SI, SS, IS, PM, LD	MMT activity patterns assessed every 20 ms
Kao et al. (1995)	Wire	LS, RH, UT, MT, LT, USA, LSA	MMT activity patterns assessed every 20 ms
Pink et al. (1990)	Wire	AD, MD, PD SI, SS, IS, PM, LD	MMT activity patterns assessed every 20 ms
Jobe et al. (1986)	Wire	AD, MD, PD, SI, SS, IS, PM, LD	MMT activity patterns assessed every 20 ms

AD – anterior deltoid; MD – middle deltoid; PD – posterior deltoid; SI –supraspinatus; SS.–subscapularis; IS – infraspinatus; PM – pectoralis major; LD – latissimus dorsi; levator scapulae; Rhomboid; UT – upper trapezius; MT – middle trapezius; LT – lower trapezius; USA – upper serratus anterior; LSA – lower serratus anterior; MMT – manual muscle test.

Normalization of the EMG data was carried out in nine studies. In six studies, the EMG values were normalized concerning the peak 1s-window (Jobe et al., 1986, 1989; Pink et al., 1990, 1993; Kao et al., 1995; Watkins et al., 1996) or 0,5s-window (Farber et al., 2009) of EMG signal during a manual muscle test (MMT), referred to as maximal voluntary contraction (MVC) or using the mean EMG amplitude during an MVC of 3-s (Glazebrook et al., 1994). Two studies including low back pain golfers normalized the EMG using a specific submaximal voluntary contraction (Horton et al., 2001; Cole and Grimshaw, 2008a). In these studies the EMG values were expressed as a percentage of the root mean square (RMS) of the EMG signal during the submaximal tests. The two other studies did not normalize the EMG signals (Bulbulian et al., 2001; Cole and Grimshaw, 2008b).

Horton et al. (2001) determined onset times as 7 standard deviations (SD) above the mean of a 200 ms window. Cole and Grimshaw (2008b) defined the onset time as muscle activity exceeding the average baseline activity by 1 SD of a 50 ms window. The offset timing parameter used the same process, but timed since the value fell below the pre-defined threshold.

Table 7
Summary of electromyographic methods used in studies performed in forearm muscles during the golf swing.

Author Year	EMG	Muscle	Normalization
Farber et al. (2009)	Wire	FCR, PT, FCU, ECRB	MMT Highest peak half-second
Glazebrook et al. (1994)	Surface	AMF, PMF	MMT Mean EMG amplitude

FCR – flexor carpi radialis; PT – pronator teres; FCU – flexor carpi ulnaris; ECRB – extensor carpi radialis brevis; AMF – anterior muscles of the forearm; PMF – posterior muscles of the forearm; MMT – manual muscle test.

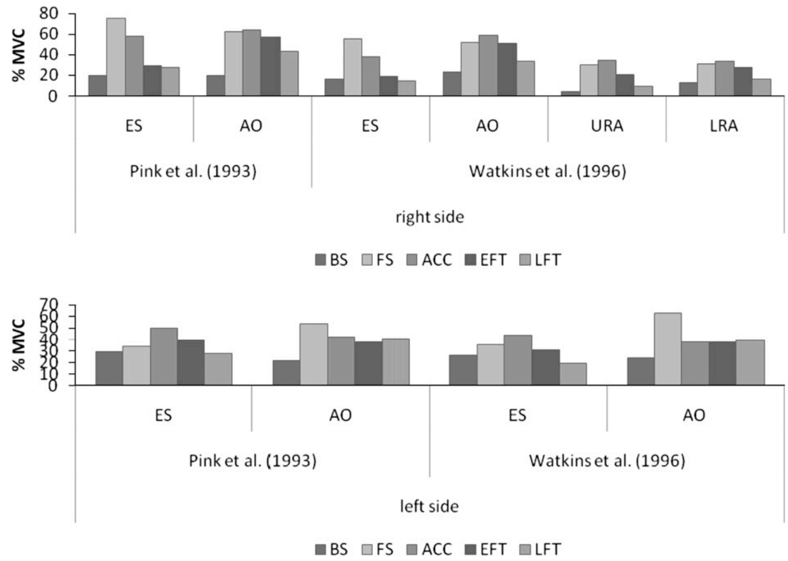

Fig. 3. Summary of muscle activity (percentage of maximal voluntary contraction [MVC]) in the trunk muscles during the different phases of the golf swing. ES – erector spinae; AO – abdominal oblique; URA – upper rectus abdominis; LRA – lower rectus abdominis; BS – backswing; FS – forward swing; AC – acceleration; EFT – early follow-through; LFT – late follow-through.

3.5. Trunk muscles – EMG results

The EMG normalized values of trunk muscles found in the retrieved papers during the different phases of the golf swing are graphically represented in Fig. 3.

The right ES had high levels of activity during the forward swing phase, while the left ES was more active in the acceleration phase (Pink et al., 1993; Watkins et al., 1996). Bulbulian et al. (2001) evaluated the influence of the *X-factor* (the differential between hips and shoulders at the top of the swing) on the EMG readings of the trunk and upper arm muscles. This study showed that when the swing was performed with a shorter backswing, the golfer presented significantly lower levels of activation in the left lumbar muscle during the forward swing phase.

Regarding the abdominal oblique (AO), the right demonstrated moderate to high levels of activity in the forward swing, acceleration and early follow-through phases while the left AO showed moderate levels of activation during the forward swing phase and weak activity during the other phases of the swing (Pink et al., 1993; Watkins et al., 1996). The results of Bulbulian et al. (2001) indicated that the external AO muscles on both sides have significantly higher levels in the swing with a long backswing than in the swing with a short backswing. The upper RA and the lower RA are recruited only at low levels during the backswing (Cole and Grimshaw, 2008a).

Cole and Grimshaw (2008a,b) compared the EMG of the trunk and abdominal muscles in golfers with and without low back pain. Low back pain golfers tended to reduce lumbar ES muscle activity at the end of the backswing. The high handicap golfers with low back pain had more lumbar ES activity and increased external AO muscle activity compared to the asymptomatic high handicap golfers.

Horton et al. (2001) compared abdominal muscle activation in professional golfers (handicap <5) with and without chronic low back pain. Abdominal muscle activation was analyzed in five maximal shots before and after a typical practice session of 50 min. The EO and RA muscles of both sides (lead and trail) showed similar activity levels in both groups. Only one significant difference was reported between groups: injured golfers exhibited EMG onset times in the lead external oblique occurring significantly later during the backswing. The control group activated its lead EO 17 ms (before practice) and 42 ms (after practice) after the start of the backswing. The chronic low back pain group activated the same muscle 56 ms (before practice) and 67 ms (after practice) after the beginning of the backswing.

3.6. Shoulder muscles – EMG results

The normalized EMG values of glenohumeral muscles found are graphically presented in Fig. 4. The PM, SS and LD from both sides were recruited at high levels. In most cases they exhibited their peak of activation during the acceleration phase (Jobe et al., 1986, 1989; Pink et al., 1990). The SS demonstrated high levels of activation during the follow-through on both sides. The other glenohumeral muscles studied (SI, IS, AD, MD, PD) showed weak to moderate levels of activation during the different swing phases (Jobe et al., 1986, 1989; Pink et al., 1990).

In the study by Jobe et al. (1989), no significant differences were found between men and women with respect to the EMG patterns, for any of the phases or any of the muscles measured.

The results of the study of Kao et al. (1995) are summarized in Fig. 5. They studied the scapular muscles and their normalized EMG values. For right handed golf players, the right serratus anterior muscle was the most active, mainly the upper portion. Both upper and lower portions peaked during the acceleration phase. The right trapezius muscle presented its highest activity level during the backswing phase, especially in the lower portion (LT). The left RH during the forward swing and the left RH and LS during the acceleration phases showed high levels of activity.

3.7. Forearm muscles – EMG results

The EMG normalized values during the different phases of the golf swing are displayed in Fig. 6. Forward swing and acceleration

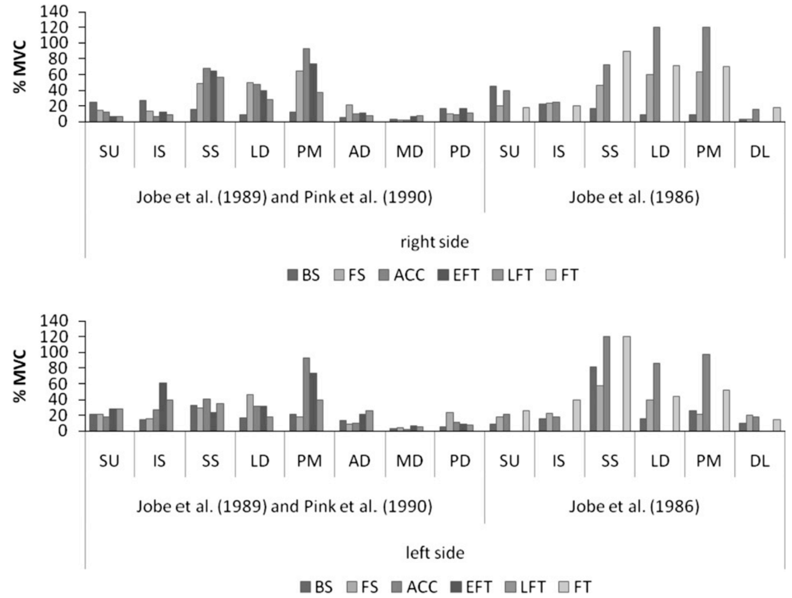

Fig. 4. Summary of muscle activity (percentage of maximal voluntary contraction [MVC]) in the glenohumeral muscles during the different phases of the golf swing. SU – supraspinatus; IS – infraspinatus; SS – subscapularis; LD – latissimus dorsi; PM – pectoralis major; AD – anterior deltoid; MD – middle deltoid; PD – posterior deltoid; DL – deltoid; BS – backswing; FS – forward swing; AC – acceleration; EFT – early follow-through; LFT – late follow-through.

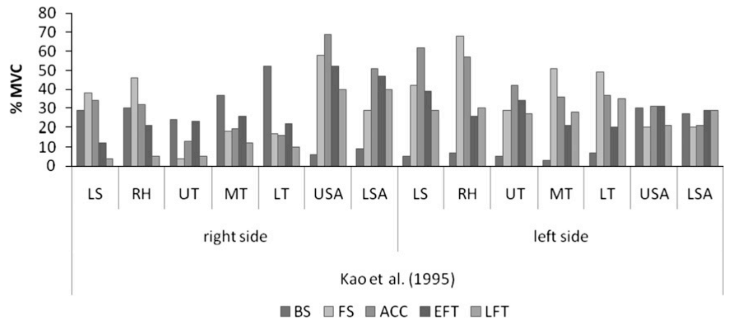

Fig. 5. Summary of muscle activity (percentage of maximal voluntary contraction [MVC]) in the scapular muscles during the different phases of the golf swing. LS – levator scapulae; RH – rhomboid; UT – upper trapezius; MT – middle trapezius; LT – lower trapezius; USA – upper serratus anterior; LSA – lower serratus anterior; BS – backswing; FS – forward swing; AC – acceleration; EFT – early follow-through; LFT – late follow-through.

were presented the highest forearm muscle activity. It is important to note that the study of Farber et al. (2009) reported EMG activity above 100% MVC, even surpassing 200%, as was the case for the FCU of the trail forearm in forward swing phase. From the comparison between the two groups of golfers, there were significant differences in the PT EMG activity. The PT muscle from the lead forearm presented a higher level of activity during the acceleration phase in professionals (88% MVC vs. 36% MVC). In the trail forearm, amateur golfers showed higher muscle activity in the PT during the forward swing phase (121% MVC vs. 57% MVC).

Glazebrook et al. (1994) measured mainly timing parameters of the swing. They found no significant differences in the swing duration between asymptomatic and symptomatic golfers, or between handicaps. They also found that the use of medial counterforce braces and oversized grips had no effect on the total swing time. Another finding of this study was that similar EMG profiles were found in the studied muscles, despite mean EMG activity being significantly different between the two groups (symptomatic and asymptomatic) whether in the address or in the swing phase, with higher levels of activity in the symptomatic subjects. There were no significant differences in mean EMG between both handicap groups. The peak activity reached by the posterior muscles of the forearm was around 60% MVC at the contact phase. The anterior muscles of the forearm demonstrated moderate activity during the first two phases but increased to 91% MVC at contact (referred by the authors as "the flexor burst").

3.8. Lower limb muscles – EMG results

Fig. 7 shows the normalized EMG values recorded by Bechler et al. (1995) and Watkins et al. (1996) during each of the golf phases. The forward swing demonstrated higher muscle activity was found in the trail lower limb when compared to the other side. Bechler et al. (1995) found that the GM was the most active muscle

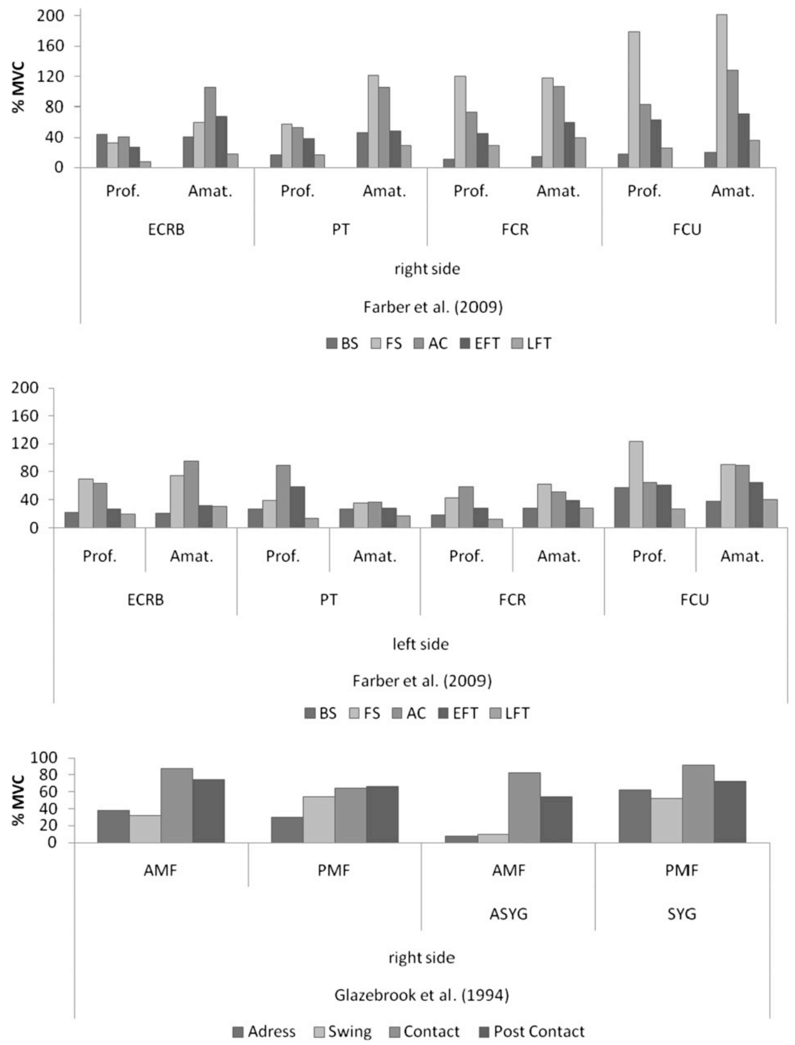

Fig. 6. Summary of muscle activity (percentage of maximal voluntary contraction [MVC]) in the forearm muscles during the different phases of the golf swing. ECRB – extensor carpi radialis brevis; PT – pronator teres; FCR – flexor carpi radialis; FCU – flexor carpi ulnaris; AMF – anterior muscles of the forearm; PMF – posterior muscles of the forearm; ASYG – asymptomatic group; SYG – symptomatic group; BS – backswing; FS – forward swing; AC – acceleration; EFT – early follow-through; LFT – late follow-through.

of the lower limb. The right GM showed high levels of activity (80–100% MVC) in the forward swing phase and the left GM presented moderate to high levels in the acceleration phase (Bechler et al., 1995; Watkins et al., 1996). A high level of activation was also found in the right biceps femoris and semimembranosus muscles during the forward swing phase (Bechler et al., 1995).

4. Discussion

The studies found showed methodological limitations. It is difficult to compare the results on muscle activation level between the studies since normalization methods used were different, i.e. submaximal muscle testing, maximal voluntary contraction or even no normalization technique applied. The studies using MVC as reference contraction did not detail the mathematical methods used. The normalization method could be obtained from the EMG peak by allowing comparison between different conditions, such as swing type or bat type but is not an EMG indicator of muscles relative activation. The use of normalization methods presented by McGill (1991) and the MVC procedures indicated by Hermens et al. (1996–1999) can be a good approach to compare studies made in different laboratories.

EMG research in the golf swing was performed both with surface and fine wire electrodes. Trunk muscles were only studied with surface EMG (Pink et al., 1993; Watkins et al., 1996; Bulbulian et al., 2001; Horton et al., 2001; Cole and Grimshaw, 2008a,b) while shoulder (Jobe et al., 1986, 1989; Pink et al., 1990; Kao et al., 1995) and lower limb muscles (Bechler et al., 1995) were recorded with fine wire electrodes. In the lower limb the gluteus maximus was recorded with surface EMG (Watkins et al., 1996). Forearm muscles were studied both with EMG methods, surface

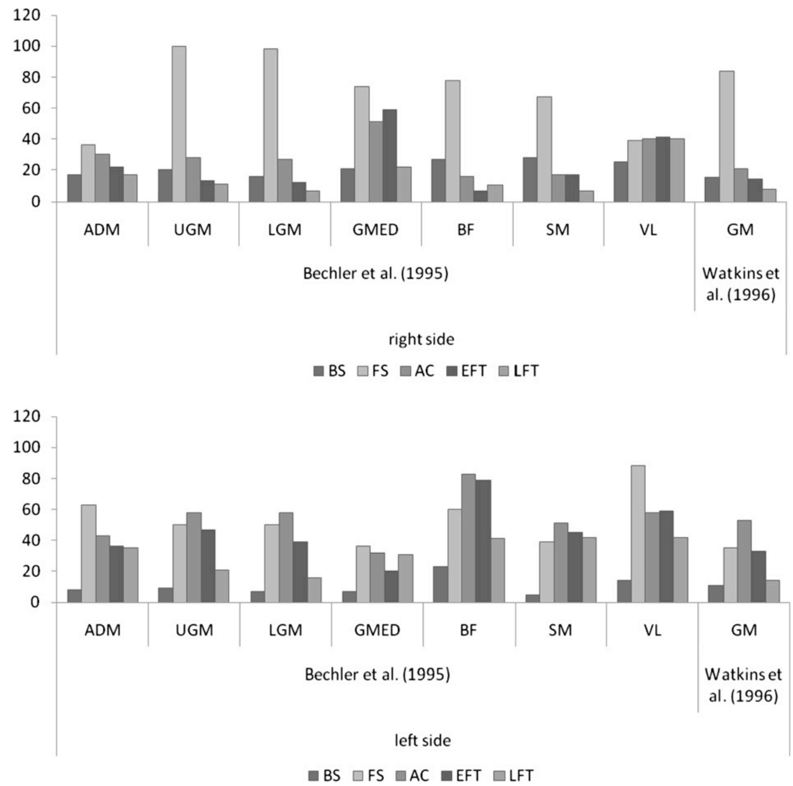

Fig. 7. Summary of muscle activity (percentage of maximal voluntary contraction [MVC]) in the lower limb muscles during the different phases of the golf swing. ADM – adductor magnus; UGM – upper gluteus maximus; LGM – lower gluteus maximus; GMED – gluteus medius; BF – biceps femoris; SM - semimembranosus; VL – vastus lateralis; GM – gluteus maximus; BS - backswing; FS – forward swing; AC – acceleration; EFT – early follow-through; LFT – late follow-through.

(Glazebrook et al., 1994) and fine wire (Farber et al., 2009). Each of those EMG techniques presents advantages and limitations that will be discussed below. Some studies did not specify the electrode placement, so it is not clear which locations were used to acquire the EMG data, resulting in difficulty in comparing values.

Only two papers (Horton et al., 2001; Cole and Grimshaw, 2008b) studied timing parameters, specifically the onset of muscle activity. Again, different methods were used concerning threshold level and time windows, making it difficult to compare values. All the other articles analyzed intensity of activation over time. Future studies could use timing parameters, such as the EMG onset or the time of maximum EMG peak, to study e.g. the influence of the level of expertise or the type of club used. Timing parameters could also be used to get information about neuromuscular coordination e.g., the proximal–distal sequence or the relationship between lead and trail upper limbs. This type of information is important during the downswing, especially in the acceleration phase, because the club head travels from horizontal to ball impact at high speeds (Lindsay and Horton, 2002). It is a very short phase (0.10 ± 0.02 s – Chu et al., 2010) where the shoulder muscles are supposed to develop great power, fundamental to the transfer of the kinetic energy from the trunk to the club.

Only two studies mentioned golf club type (Horton et al., 2001; Bulbulian et al., 2001) used during the swing but Bulbulian et al. (2001) compared the muscular activity between swing types. Egret et al. (2003) studied swing kinematics with three different clubs (driver, five-iron and pitching wedge). They reported an identical movement time and proportion for each phase of the swing performed with different clubs, but the kinematics and the club head speed were different depending on the clubs used. No studies about the influence of using different clubs on EMG patterns were found.

We found only one paper that compared the EMG activity in golfers with different handicaps (Farber et al., 2009). Most of the studies were performed on highly skilled golfers, i.e. professionals or low handicap amateurs. This means that most of the EMG research conducted does not reflect the neuromuscular patterns of the average player, with a less reproducible and efficient golf swing. It is therefore important to conduct studies in lower level golfers, since they represent the majority of the population playing golf. The characteristics of the average golf player are little known, and may present potential for injuries probably because of the lesser level of conditioning. For example, the study of Farber et al. (2009) showed significant differences in the forearm muscle activity between golfers with different handicaps that could be associated with a high incidence of injuries in high handicap golfers. Additionally, there is a lack of studies on women, although it is recognized that male golfers may have different playing behaviors and injury risks from women. So, future research should compare muscle activity in other body segments between players of different levels and also study the muscular patterns during the swing golf performed by women.

4.1. Trunk muscles

Trunk muscle strength and coordination are considered to be vital for both the professional and the recreational golfer demanding a high muscular solicitation during the trunk rotation, especially during the forward swing phase to drive power to the ball (Watkins et al., 1996). The "controlled fall" of the club with the rotation of the trunk (from right to left on right handed golfers) builds up the club head velocity, increasing kinetic energy transfer to the ball and thus achieving longer distances (Pink et al., 1993). Some of the EMG studies report that trunk muscle activity increases during the downswing and the acceleration phase, mainly in the right erector spinae and oblique abdominal muscles (Pink et al., 1993; Watkins et al., 1996).

Trunk injuries, especially low back pain (LBP), represent the most common musculoskeletal complaint during all swing phases, mainly at the end of the backswing (Cabri et al., 2009). Repetitive golf swings may increase pain in the low back area in symptomatic subjects (Horton et al., 2001). LBP is a common musculoskeletal disorder affecting a high percentage of people, including golfers. Little is known about the specific mechanisms responsible for LBP (Lindsay and Horton, 2002). Furthermore, it is unclear whether golf practice is causing or aggravating LBP, or whether LBP is inducing lower levels of golf practice. It is commonly accepted that weakness, lack of endurance and low resistance to fatigue of the abdominal and back muscles could represent significant risk factors in the occurrence of chronic LBP (Lindsay and Horton, 2002). Previous research found that, compared with the pain-free control group, golfers with LBP present important differences in spine movement (Lindsay et al., 2000) and in the intensity and timing of EMG activation of trunk muscles such as the lumbar erector spinae and abdominal oblique muscles (Horton et al., 2001; Cole and Grimshaw, 2008a,b). Those differences were evident mainly during the backswing and downswing, specifically, in the recruitment of the erector spinae in the beginning of the backswing as was observed by Cole and Grimshaw (2008a,b). The authors interpreted this anticipation in the recruitment of the erector spinae as a lumbar spine stabilizer instead of the deeper muscles such as the multifidus and transversus abdominis. This change in coordination patterns may contribute to spinal instability when considering the higher external abdominal oblique activity developed by golfers during the swing (Pink et al., 1993; Watkins et al., 1996).

The papers previously mentioned comparing golfers with and without LBP used surface EMG. No studies were found using fine wire electrodes to observe spine and pelvis stabilizers, such as the transversus abdominis and multifidus muscles. These muscles are considered to be active prior to rapid movements of the upper and lower limbs (Marshall and Murphy, 2003). Furthermore, no available data were found concerning the iliopsoas, supposedly a powerful muscle playing an important role in lumbar mechanics. But it may be difficult to obtain data because of its deep fascia localization and the movement speed.

Clockwise rotation of the trunk during the backswing stretches the trunk muscles, thus facilitating their action in the forward swing phase (Pink et al., 1993). The end of the backswing phase is referred as the time where complaints of pain are more often reported especially due to over-rotation (Cabri et al., 2009). The over-rotation manoeuvre, usually performed by high level golfers, is believed to produce higher club head speed and to maximize flight distance of the ball. But it probably causes high load in the lumbar spine and increases the risk of injury. The study of Bulbulian et al. (2001) showed that a shorter backswing exhibited lower levels of activation in the abdominal muscles involved in the trunk rotation while was found an increase in the muscles responsible for arm acceleration, such as the latissimus dorsi and pectoralis major, during the downswing.

The relationship between the magnitude of the *X-factor* and the EMG activity patterns has not been studied. The relationship between the magnitude of the *X-factor* and the inter-muscular coordination pattern of the trunk rotator muscles may be an important issue to explore in future research.

4.2. Shoulder muscles

With respect to the muscles acting on the glenohumeral joint, the most active muscles were the pectoralis major, the latissimus dorsi and the subscapularis which peak during the acceleration phase (Jobe et al., 1986, 1989; Pink et al., 1990). All studies showed a minimal to low participation of the deltoids during the golf swing (Jobe et al., 1986, 1989; Pink et al., 1990).

The serratus anterior muscle was the most active muscle in the trail shoulder and its maximum activity was obtained during the acceleration phase, probably related to scapula abduction. The high level of activity of the right trapezius (in right-handed golfers) during the backswing phase, which was more pronounced in the lower portion, could be related to the combination of scapula adduction and superior rotation, necessary to position the glenoid fossa during humerus abduction. The scapular adductors of the opposite side were most active muscles during the forward swing and acceleration phases (Kao et al., 1995).

Shoulder injuries were reported as being most common in both professionals and amateur golf players (McCarroll and Mallon, 1994; Kim et al., 2004; McHardy et al., 2006; Cabri et al., 2009) affecting mainly the non-dominant shoulder (Pink et al., 1990). The rotator cuff muscles, responsible for the dynamic stability of the glenohumeral joint, play an important role in positioning and stabilizing the humerus in the athlete's shoulder (Blevins, 1997; Kao et al., 1995), mainly if repeated movements are performed with great amplitude and/or velocity. The findings of Jobe et al. (1986, 1989) and Pink et al. (1990) showed that during the backswing the subscapularis is the most active shoulder muscle in the lead arm and that the infraspinatus and supraspinatus act together as external rotators, abductors and glenohumeral stabilizers, with higher EMG activity at extreme ranges of motion of the shoulder at the end of the backswing and follow-through phases. The literature indicates that shoulder overuse injuries are related to excessive shoulder rotation produced during these swing phases (Theriault and Lachance, 1998).

The afore mentioned studies used fine wire electrodes, even in the superficial muscles such as the deltoid, pectoralis major, latissimus dorsi and trapezius. The EMG signal obtained with this method is mainly dependent on the action potential from the fibers positioned more closely to the detection electrode. However, there is a lack of studies of the shoulder muscles measured with surface EMG, which is considered to be more representative of the overall myoelectric activity produced by the muscle during the swing.

4.3. Forearm muscles

Farber et al. (2009) found significantly higher peak activity in the leading pronator teres during the acceleration phase and just after the impact in professional golfers compared to amateur players who showed a peak activation in the extensor carpi radialis brevis (Farber et al., 2009). This study also reported considerably higher levels of activity in the extensor carpi radialis brevis in amateurs during all swing phases, except during the takeaway. The higher activity observed in the forearm muscles can be related, to the higher incidence of medial epicondylitis of the trail elbow and lateral epicondylitis of the lead elbow found in amateur golfers (Cabri et al., 2009). Future studies should explore this hypothesis.

In contrast, Glazebrook et al. (1994) did not find differences in forearm EMG patterns between golfers with different handicaps. The absence of differences could be related to the fact that this study used surface electrodes, which are considered to be less selective. Due to the small volume of the forearm muscles, recording EMG of isolated forearm muscles with surface electrodes has a high probability of crosstalk from other muscles. This methodological difficulty is probably related to the lack of EMG studies conducted on the muscles of the elbow and wrist. To reduce cross-talk influence in the EMG signal recorded with surface electrodes, the double differential technique was proposed (De Luca, 1997). A surface electrode containing three detection surfaces and two levels of differential amplification was developed for this purpose. Alternatively, some adaptations in the electrodes design can be made, for example by reducing the size and distance between the detection surfaces (interelectrode distance).

It is also important to point out that the afore mentioned studies (Glazebrook et al., 1994; Farber et al., 2009) were performed only on male golfers. Since there are important differences between upper limb muscle profile and strength capacity between genders (Miller et al., 1993) we cannot transfer the results of these studies to the female golfer. Thus, future research about forearm coordination patterns in golf swing performed by female golfers is desirable.

4.4. Lower limb muscles

Very little research about lower limb muscle activity is available. One study analysing the EMG patterns in the golf swing using single-needles, (Bechler et al., 1995) focused only on the muscles acting on the hip and knee joints. Generally speaking, high activity in the trail leg was found during takeaway and forward swing whereas during acceleration and follow-through higher activity in the lead leg was observed. In both legs, the hip extensors showed the highest level of activation. Another study (Watkins et al., 1996) studied the gluteus maximus but was rather focussing on trunk muscle activation.

No available literature was found on the muscles acting on the ankle. However, the foot/ankle region is one of the most injured regions in golfer players (McHardy et al., 2007). Therefore, it would be useful to investigate neuromuscular mechanisms related to weight transfer during the swing as well as the stabilization role of muscles crossing the ankle joint.

5. Conclusions

This literature review found 19 papers that matched the defined search criteria: six on the trunk, four on the shoulder muscles, two on the forearm, one on the lower limbs and six literature reviews. There is only one literature review, which centered on EMG patterns in the golf swing (McHardy and Pollard, 2005a). The review performed provides a basis of knowledge about the neuromuscular patterns in the golf swing, but a number of limitations must be considered regarding comparisons of studies performed in different laboratories. These limitations are related to the heterogeneity in the golfers studied and differences in, or lack of information on the EMG methods used. For example, the local placement of the surface electrodes is different in the studies found. There is an absence of specific information on the methodology used to determine the maximal voluntary contraction to normalize the EMG signals. In the few studies that analyzed timing parameters there is also no clear information about the criteria used to define timing parameters, e.g. times of EMG onset and offset.

One of the most important questions is the influence of different types of golf clubs on neuromuscular patterns because some differences in the kinematics and club head speed were found.

There is also a need to characterize the muscular participation during the swing in more distal regions of the limbs, i.e. the muscles acting on the ankle, elbow and wrist, since those regions have a considerable potential for injury.

In the future would be important to perform EMG in less skilled golfers, since they are the majority of the population playing golf. Additionally, particular interest should be attributed to the female golfer.

Finally, most studies evaluated only EMG amplitude parameters. Only two studies that evaluated timing parameters on trunk muscles were found. This dimension to understand how the central nervous system controls the coordination patterns between the different muscles and adapts to different constraints such as the type of golf club or different game strategies.

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Capítulo 4

Estudo II

Caraterização da participação muscular do membro superior dominante durante o swing em jogadores de baixo handicap

Este capítulo foi um estudo de caso de caráter experimental para futuros estudos, por esse motivo foi redigido em Inglês.

EMG pattern of the dominant upper limb muscles in different variations of the golf swing: a descriptive approach.

Purpose: The main purpose of the present study was to characterize the neuromuscular activation pattern of the dominant upper limb in three common variations of the golf swing: normal full swing with a normal amplitude and preferred tempo, a swing with a slower tempo, and a swing with lower backswing amplitude.

Methods: Three low-handicap golfers (handicap≤5) performed golf swings with a pitch iron, under three different conditions: full swing (*F Swing*), swing with a target speed of 90% of the full swing speed (*S Swing)*, and swing with a short backswing amplitude and 90% of the full swing speed (*¾ Swing*). Four trials of each type of swing were selected for analysis. Surface electromyography (EMG) was recorded from 12 muscles: anterior (AD), middle (MD) and posterior (PD) deltoids, pectoralis major (PM), latissimus dorsi (LD), infraspinatus (IS), vastus lateralis (VL) and long portion (LP) of triceps brachii, biceps brachii (BB), brachioradialis (BR), wrist flexors (WF) and wrist extensors (WE). The EMG signals were normalized using the EMG of the maximal voluntary contraction (MVC) as a reference. In synchrony with the EMG signals, a three axis accelerometer fixed at the back of the golf club head informed about the moment of contact with the ball (BC). For the movement analysis and phase delimitation the swing was filmed with four high speed video cameras (300 Hz). The recording of EMG and kinematic data was performed with a SIMI Motion system. For each muscle we calculated the time of maximum EMG peak and mean EMG normalized value (%MVC) during backswing *(BS),* downswing *(DS)* and follow-through *(FT).* We also registered the EMG onset and offset for the muscles with a main burst of activity during the DS phase. To determine the onset and offset, automatic routines were used, using the minimum value before and after 80 ms of the muscle maximums. This was an exploratory study with a limited sample of 3 subjects, therefore descriptive statistics (mean, SD, and coefficient of variation) were adopted for analysis.

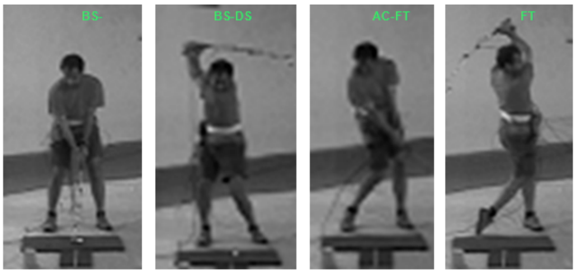

Figure 1 – The swing was divided in three phases: *backswing, downswing* and *follow-through*.

Figure 2 – Subject with surface EMG electrodes in the dominant upper limb.

Results: The muscles which showed higher values of the average normalized EMG during the *DS* phase were the PM (28-46%), LD (33-56%), VL (30-59%), LP (40-56%) and WF (31-76%). Those muscles showed their EMG onset 220 to 400 ms before BC. The EMG peak of the arm adductors (PM, LD) and elbow extensors (VL, LP) occurred 160 to 30 ms before BC. The WF peaked later, ranging from 50 ms before BC to 30 ms post BC. A tendency-increased intensity of EMG activity during the *F Swing* when compared with the *S Swing,* was observed in the VL, LP, LD and AD muscles. During *BS*, the most intense muscular activity was observed in the elbow flexors (BR 21-70%; BB 14-42%), WE (14-38%) and IS (17-36%). The timing of the maximum EMG peak in the elbow flexors presented great variation (850 to 500 ms BC) but in the case of WE and IS it was observed between 550 and 450 ms before BC. The WF (18-43%) and the AD (8-60%) dominated the FT phase. Some muscles (AD, BR) presented great variability in the EMG intensity and/or timing structure in the different subjects.

The EMG activity timing had a higher inter subject and group variability. The VL muscle had a higher timing in the ¾ swing in subject 1, 2 and group. The LP muscle had a higher timing in the ¾ swing in subject 1, 2 and group. For the same muscle less timing was observed in the F swing in subject 1, 2 and group. For the WF muscle less timing was seen in the F swing in subject 2, 3 and group. The LD muscle had a tendency behavior in the F swing for less timing in all subjects and group.

Table 1 – Mean values of each subject for: normalized EMG (%EMG), standard deviation (SD), coefficient of variability (CV), time interval between maximum EMG and ball contact (TmaxEMG), time interval between EMG onset and ball contact (EMG Onset) and time of EMG activity (EMG activity). It is also referred the phase were the maximum EMG peak was found (Phase MaxEMG). Muscles: vastus lateralis (VL) and long portion (LP) from the triceps brachii, latissimus dorsi (LD), pectoralis major (PM) and wrist flexor (WF) during backswing, downswing and follow through phases.

Backswing Phase													
		Subject 1			Subject 2			Subject 3			Group		
Muscle	Swing Type	S	F	3Q	S	F	3Q	S	F	3Q	S	F	3Q
PD Muscle	%EMG	53,95%	71,31%	66,71%	72,08%	76,47%	59,00%	11,39%	13,72%	12,30%	45,81%	53,83%	46,00%
	SD	17,59%	9,74%	17,48%	9,58%	4,09%	7,14%	0,29%	1,54%	2,85%	31,15%	34,83%	29,44%
	CV	32,62	13,65	26,21	13,3	5,35	12,09	2,51	11,21	23,18	68,01	64,71	64
	TmaxEMG (ms)	-52,75	-58,25	-34,5	113	82,5	109,5	-909,8	-735	-800,7	-283,2	-236,9	-241,9
	SD	14,33	31,3	21,67	4,32	14,84	26,74	48,87	122,52	38,02	548,93	437,06	489,24
BB Muscle	%EMG	13,76%	15,67%	15,71%	16,10%	15,56%	13,86%	41,08%	42,05%	34,17%	23,65%	24,43%	21,25%
	SD	0,67%	3,11%	4,35%	2,68%	1,68%	1,80%	2,48%	1,76%	4,71%	15,14%	15,26%	11,23%
	CV	4,9	19,83	27,7	16,64	10,77	13,02	6,02	4,19	13,77	64,03	62,47	52,85
	TmaxEMG (ms)	-540,8	-499,3	-519	-746	-96,33	-559,3	-840,3	-800	-728,3	-709	-465,2	-602,2
	SD	31,66	12,42	38,43	225,11	249,99	409,9	38,22	67,81	78,28	153,14	353,07	111,03
WE Muscle	%EMG	16,96%	18,31%	13,83%	19,25%	18,77%	17,10%	35,55%	38,43%	32,15%	23,92%	25,17%	21,02%
	SD	3,26%	2,30%	1,85%	2,04%	0,31%	1,05%	3,16%	2,11%	4,80%	10,14%	11,48%	9,77%
	CV	19,24	12,54	13,36	10,62	1,66	6,14	8,89	5,49	14,92	42,39	45,62	46,47
	TmaxEMG (ms)	-526	-449,8	-542,8	-29,67	-3,67	-28,33	-528	-460,8	-490	-361,2	-304,7	-353,7
	SD	29,13	32,88	34,3	24,17	29,67	14,19	25,24	50,78	44,24	287,14	260,78	283

Downswing Phase													
		Subject 1			Subject 2			Subject 3			Group		
Muscle	Swing Type	S	F	3Q	S	F	3Q	S	F	3Q	S	F	3Q
LD Muscle	%EMG	40,14%	51,92%	32,85%	52,53%	55,75%	48,64%	48,62%	54,51%	52,12%	47,10%	54,06%	44,53%
	SD	6,64%	8,83%	4,56%	5,17%	10,57%	4,34%	7,36%	5,26%	9,89%	6,34%	1,95%	10,27%
	CV	16,54	17,01	13,87	9,85	18,97	8,92	15,14	9,65	18,98	13,45	3,61	23,06
	TmaxEMG (ms)	-77,25	-91	-62,25	-154,3	-144,7	-162	-134	-150,3	-124,5	-121,8	-128,6	-116,3
	SD	20,12	9,42	31,48	15,73	8,39	26,76	8,83	13,6	5,07	39,92	32,72	50,38
	EMG Onset (ms)	-325	-244,5	-328	-317	-275	-336	-317	-303,3	-297,8	-319,7	-274,3	-320,6
	SD	46,64	12,4	17,57	11,36	18,19	13,98	43,23	8,62	6,85	4,62	29,38	20,17
VL Muscle	%EMG	42,69%	50,46%	45,05%	29,84%	41,56%	37,29%	47,42%	49,19%	59,21%	39,99%	47,07%	47,18%
	SD	5,40%	5,52%	6,90%	1,54%	3,85%	2,18%	7,65%	8,70%	9,48%	9,09%	4,81%	11,11%
	CV	12,66	10,94	15,31	5,17	9,25	5,85	16,12	17,69	16,02	22,75	10,23	23,55
	TmaxEMG (ms)	-97	-111,3	-95,25	-80,5	-83	-108,5	-102,3	-96	-107,8	-93,25	-96,75	-103,8
	SD	17,42	16,3	7,89	7,51	13,11	31,12	16,78	12,33	17,82	11,35	14,14	7,44
	EMG Onset (ms)	-275,7	-377,8	-256,7	-237,5	-235,3	-249	-252,5	-254,8	-276	-255,2	-289,3	-260,6
	SD	2,89	52,24	16,17	11,56	18,72	36,26	18,5	5,91	12,57	19,23	77,23	13,91
WF Muscle	%EMG	74,02%	76,14%	64,17%	30,98%	37,79%	40,46%	34,55%	30,96%	38,95%	46,52%	48,30%	47,86%
	SD	4,83%	7,53%	23,24%	8,12%	2,68%	5,24%	3,64%	3,70%	4,30%	23,89%	24,35%	14,14%
	CV	6,53	9,88	36,21	26,21	7,09	12,96	10,54	11,94	11,04	51,35	50,43	29,55
	TmaxEMG (ms)	-46,75	-34,5	-52,67	-32,5	-24,33	-257,3	23,5	26,75	-12,25	-18,58	-10,69	-107,4
	SD	20,17	3,54	15,01	16,26	34,78	37,17	36,85	16,6	57,13	37,14	32,82	131,39
	EMG Onset (ms)	-252,5	-288	-281,3	-189,5	-184	-586,7	-217,8	-217,3	-229	-219,9	-229,8	-365,7
	SD	29,92	32,53	86,19	12,02	74,81	38,55	9,54	11,44	9,38	31,56	53,11	193,17

Follow-Through Phase													
		Subject 1			Subject 2			Subject 3			Group		
Muscle	Swing Type	S	F	3Q	S	F	3Q	S	F	3Q	S	F	3Q
AD Muscle	%EMG	10,60%	17,07%	8,17%	32,57%	60,39%	31,24%	11,24%	15,01%	8,82%	18,14%	30,82%	16,08%
	SD	2,70%	1,85%	1,25%	3,40%	5,12%	2,70%	1,81%	1,31%	1,43%	12,50%	25,62%	13,14%
	CV	25,43	10,83	15,34	10,45	8,47	8,63	16,06	8,73	16,21	68,95	83,13	81,71
	TmaxEMG (ms)	355,75	369,5	363,25	382,33	331	331	-59,33	-57,25	-75,25	226,25	214,42	206,33
	SD	84,15	50,2	23,96	7,37	5,66	32,69	13,61	4,5	14,36	247,68	236,06	244,39
WF Muscle	%EMG	63,72%	49,35%	57,38%	22,56%	28,40%	17,61%	38,31%	43,37%	37,10%	41,53%	40,38%	37,36%
	SD	9,68%	18,55%	17,45%	3,25%	1,42%	3,12%	3,00%	3,97%	5,50%	20,77%	10,79%	19,89%
	CV	15,2	37,59	30,41	14,41	4,99	17,74	7,84	9,15	14,82	50,01	26,73	53,23

Conclusions: The average EMG during each phase and the timing of the EMG onset and offset and maximum peak showed that the shoulder adductors, elbow extensors and wrist flexors were the most important muscles of the dominant arm in the downswing in the three experimental conditions. The results also revealed the importance of an individual analysis subject by subject when we are processing timing parameters. The gathered data has to be analysed before forming a group. The CV values were lower in each subject than in the group suggesting that some muscles may exhibit high variability between trials and conditions, being difficult to affirm that there is or there is not a standard. This aspect claims for further research.

Capítulo 5

Estudo III

Análise eletromiográfica dos músculos do tronco

durante o swing do golfe realizado com dois tipos de taco diferentes

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Electromyographic Analysis of Trunk Muscles during the Golf Swing Performed with Two Different Clubs

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ABSTRACT

The aim of this study was to compare the EMG patterns of trunk muscles throughout the golf swing, performed with two different clubs, and also to describe the activity patterns in the average golfer.

Nine male golfers performed ten swings using the pitching wedge and the 4-iron, alternately. Surface electromyography (EMG) was recorded from trunk muscles of both sides: rectus abdominis (RA), external oblique (EO), erector spinae (ES) and gluteus maximus (GM). 3D high-speed video analysis was used for determination of golf swing phases. Muscles had their highest activation during the forward swing and acceleration phases. The highest mean activation regarding the maximal EMG (EMG_{MAX}), was found in the right EO (59-67% EMG_{MAX}) and in the GM of the trailing leg (62-72% EMG_{MAX}). In the majority of the cases and phases, trunk muscles showed higher mean values of EMG activation when golfers performed with 4-iron club. However, no club effect was verified in trunk muscles.

Key words: EMG, Golf Swing, Surface Electromyography, Trunk Muscle Activity

INTRODUCTION

The golf swing is a complex movement that has the goal of transmitting power to the ball in order to produce the desired ball trajectory[1], to achieve greater distances and is responsible for the majority of golf related injuries[2-5]. The golf swing demands higher trunk muscle activation (associated with trunk rotation), especially during the forward swing and acceleration phases, and is pointed out to be vital, by both professional and recreational golfers[6]. The so-called "controlled fall" only occurs during the early downswing phase. There is little build-up or transfer of kinetic energy of the trunk to the club during this time[7]. Previous research investigated the EMG trunk muscles (rectus abdominis, external abdominal oblique, and the erector spinae muscles) activation levels during the golf swing[6-10]. Trunk

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muscle activity increased during the forward swing and the acceleration phase, mainly the erector spinae and the external oblique abdominal muscles of the right side[6,7]. However, six EMG studies[3-5,8-10], mentioned the influence of club type for the purposes of data collection. A previous study[9] reported significant differences in the erector spinae muscle between low-handicap golfers with- and without low back pain at impact and between high-handicap golfers with- and without low back pain at the end of the backswing/start of the downswing. Egret et al.[11] compared the swing kinematics of three different clubs (driver, 5-iron and pitching wedge) in experienced low handicap (0-3) golfers. They reported an identical movement time and proportion for each swing phase performed with different clubs, whereas the kinematics and the club head speed were different. Since the trunk movement is important to produce an angular momentum during the golf swing, we have to consider that the use of different types of clubs could affect the trunk muscle pattern demand.

Most of the EMG research reflected the neuromuscular patterns of the professional golfer but the majority of the population are average players, with a less reproducible and efficient golf swing. The characteristics of the average player are little known, and may present potential injuries probably because of the lesser level of conditioning.

This study tested the hypothesis of differences in trunk muscles activation between clubs. The aim is to compare the EMG patterns of trunk muscles throughout the golf swing performed with a long iron (4-iron) and with a short iron (pitching wedge), as well as describe the neuromuscular patterns, in each phase, on the average golfer.

METHOD

SUBJECTS

Nine volunteer male and right-handed recreational golfers were recruited. The mean age was of 52.0±7.4 years (range 34-61 years) with handicap of 15.7±3.2, height of 1.75±0.1 m and mass of 73±8.6 kg. The sample consisted of recreational golfers, with varied experience, different practice habits and handicap ranging from 11 to 20 (see Table 1). The subjects showed no limitations for golf practice and agreed to complete the investigation protocol. The Research Ethics Committee of the Faculty of Human Kinetics from the Technical University of Lisbon approved the study. After the explanation of study purposes and collection steps, the subjects signed the consent form and answered a brief questionnaire about their characteristics.

Table 1. Subjects Characteristics (n=9)

Characteristics	mean ± SD	range
Age (yr)	52.0±7.4	34.0–61.0
Height (m)	1.8±0.1	1.64–1.90
Body Mass (kg)	73.2±8.6	64.0–91.0
Handicap	15.7±3.2	11.0–20.0
Experience (yr)	10.6±5.6	3.0–18.0
Training history (hr/week)	1.4±1.0	0.1–3.0

TASK

The subjects were instructed to perform five accuracy shots with the pitching wedge (<100 m) and five long distance shots with the 4-iron (>150 m), at random sequence. Before the experimental procedures, all subjects were allowed to perform some practice trials to provide a better adaptation to the task. The two clubs had graphite shafts of standard length. The swings were performed on an artificial turf golf mat with high shock absorption characteristics. Subjects were advised to take into consideration their average distances with the two clubs, performing each shot as realistically as possible.

VIDEO DATA RECORDING, PROCESSING AND ANALYSIS

Video analysis was used for determination of golf swing phases. Data was recorded by three Basler A602fc (Basler Vision Technologies, Ahrensburg, Germany) high-speed cameras at 100Hz, and a fourth camera Casio EX-FH20 (Casio, Tokyo, Japan) of 1000Hz placed near the ball to determine the impact instant. Two reflective markers were placed in the shaft extremities of the club, according to Horton et al.[10], to determine the swing phases. For 3D kinematic analysis SIMI Motion 3D system (SIMI Reality Motion Systems GmbH, Unterschleissheim, Germany) was used. Video data was synchronized with EMG data to divide the golf swing into five phases, as previous literature described[6,7,12]: 1) the Backswing – from the address to top of the swing; 2) the Forward Swing – from the top of the swing to the horizontal club (early part of Downswing); 3) the Acceleration – from the horizontal club to impact (late part of Downswing); 4) the Early Follow-Through – from the impact to horizontal club; 5) the Late Follow-Through – from the horizontal club to the completion of the swing.

EMG DATA RECORDING, PROCESSING AND ANALYSIS

Electromyographic signals were collected with active electrodes (PLUX, Lisbon, Portugal) and telemetric equipment bioPLUX® research 2010 (PLUX, Lisbon, Portugal). Sensors amplified the EMG signals with a bandpass (10-500 Hz), common-mode rejection ratio (CMRR) of 110 dB and input impedance greater than 100 MΩ. All EMG data were sampled at 1000 Hz, digitally filtered (10-490Hz), full wave rectified, smoothed through a low-pass filter (12 Hz, fourth-order Butterworth digital filter), and amplitude normalized using the peak 1-second EMG signal during EMG_{MAX}, as reference. The average value of EMG signal during each phase of the golf swing was calculated for each repetition, condition and subject. EMG data processing was performed using a routine by MATLAB® software V.R2010a (The Mathworks Inc., Natick Massachusetts, USA). The quality of the signals was guaranteed by visual inspection by experienced researchers prior to EMG processing.

In order to decrease the impedance of the interface between skin and electrode, skin was prepared by hair removal, skin abrasion and alcohol cleaning. The electrodes were aligned with muscle fiber orientation with a center-to-center distance of 20 mm, at the most prominent part of the muscle bellies taking into account the following references: Rectus Abdominis (RA) 3cm lateral to the umbilicus; External Abdominal Oblique (EO) 15cm lateral to the umbilicus; Erector Spinae (ES) 3cm lateral to the L3 spinous process; and Gluteus Maximus (GM) on the mid-line between the sacral and greater trochanter corresponding to greatest prominence of the middle buttocks[10]. The ground electrode was placed over the manubrium sterni.

Two maximum voluntary contractions (MVC), of 3 to 4 sec, were performed for each muscle in order to allow the signal normalization. The MVC protocols were: RA – subject tried to perform spine flexion at 30° in a supine position on the couch with knees bent at 90° and feet at the floor, one investigator performing the manual setting of bilateral lower limbs while another investigator fixed the shoulder subject; EO – lateral position with the legs bent and supported in the marquise set by the investigator, hands on the chest, the subject produced a maximum isometric trunk lateral flexion against a resistance offered by another investigator; GM – placed in the pronated position with hands at the forehead, the opposite leg and lower back fixed, the subject was instructed to perform 20° of thigh extension in external rotation against the manual resistance offered by the researcher; ES – prone position with extended lower limbs and pelvis attached on the couch, the subject performed trunk extension against bilateral resistance at shoulders offered by the investigator. Participants were verbally encouraged during the maximal isometric efforts and in order to avoid fatigue 2min rest was allowed between repetitions. EMG normalizing procedure was consistent with procedures described by Konrad[13] and McGill[14].

STATISTICAL ANALYSIS

Data were processed in IBM SPSS Statistics 19.0 (IBM Corporation, New York, USA) software. The significance level was set at 5%. Descriptive statistics were reported as mean±SD. Data were tested for normality with the Shapiro-Wilk test and no serious violations to the normality were noted ($p>.05$). A two-way repeated measures ANOVA was conducted to explore the impact of two club types (pitching wedge and 4-iron) on normalized values of EMG muscle activity, during the five swing phases. The analysis was performed separately for each muscle and phase. Due to the reduced sample size, alpha level was adjusted to .005. When necessary, the post-hoc analysis was carried out with Bonferroni test. The additional assumption of sphericity was assessed by the Mauchly's test, and the degrees of freedom were corrected using Greenhouse-Geisser estimates when it was violated.

RESULTS

Table 2 presents descriptive statistics of normalized values of EMG activity of studied muscles for both clubs (4-iron and pitching wedge) during different swing phases.

Figure 1 shows profile plots of marginal means of EMG percentage values of EMG_{MAX} of each muscle in different phases for both clubs.

Table 3 presents the results of the two-way repeated measures ANOVA for the three effects (club x swing phase interaction, club and swing phase) by muscle laterality.

COMPARISON BETWEEN CLUBS (4-IRON AND PITCH)

The activation patterns were identical between clubs. For all studied muscles, there were no significant interactions between the clubs ($p>.005$). However, a general tendency was observed for higher mean values of EMG_{MAX} in the swing performed with the 4-iron club, especially in the right EO (e.g., in the Acceleration phase the pitch club showed 42% EMG_{MAX} while the 4-iron club exhibited 63% EMG_{MAX}).

COMPARISON BETWEEN PHASES

All muscles showed low or medium levels of activity (5 – 32% EMG_{MAX}) during the Backswing phase, in both clubs. The right RA, left RA, right EO, left EO, right ES and right GM muscles reached the peak in the Forward Swing while in the left ES and left GM peak occurred in the Acceleration. In the Early Follow-Through and Late Follow-Through, all muscles decreased activity (8 – 35% EMG_{MAX}).

Three significant differences were found between phases: 1) in the right RA between the Backswing and Early Follow-Through ($p=.002$); 2) in the right EO between the Forward Swing and Late Follow-Through ($p=.004$); 3) in the left GM between the Acceleration and Late Follow-Through ($p=.004$). The right and left ES, as well as the right GM presented a significant statistical difference ($p\leq.001$) between phases but the reduced sample conditioned the Bonferroni test.

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Table 2. EMG (%EMG_{MAX}) by Muscle Laterality and by Club on Each Swing Phase

mean ± SD		swing phase									
		Backswing		Forward Swing		Acceleration		Early Follow-Through		Late Follow-Through	
muscle	side	pitch	4-iron	pitch	4-iron	pitch	4-iron	pitch	4-iron	pitch	4-iron
RA	left	5±2.9	6±3.0	23±16.8	26±16.7	17±12.4	19±11.7	17±10.6	18±7.3	8±4.7	10±5.2
	right	5±2.2	5±2.2	40±26.2	42±23.4	14±7.8	17±6.8	19±8.9	22±9.6	12±6.8	13±6.0
EO	left	29±17.6	30±17.5	41±19.8	44±19.7	29±20.0	28±17.8	27±15.9	28±17.3	24±10.7	28±14.8
	right	23±1.8	32±23.5	59±21.9	67±18.8	42±19.6	63±30.8	40±15.5	50±14.0	35±15.6	40±16.7
ES	left	26±17.9	23±13.5	28±10.4	29±10.1	38±16.0	41±17.7	16±9.4	17±11.2	17±10.0	18±12.4
	right	21±9.2	20±8.5	36±13.1	38±15.7	26±13.4	30±13.8	13±3.8	15±5.8	17±11.2	18±12.5
GM	left	15±5.9	15±4.8	24±12.6	25±12.6	52±24.0	60±29.3	31±17.1	36±24.3	12±6.1	15±10.0
	right	10±5.8	10±4.7	62±32.3	72±38.4	26±20.9	29±20.2	19±15.1	19±14.7	15±8.9	22±18.5

Legend: RA – rectus abdominis, EO – external abdominal oblique, ES – erector spinae, GM – gluteus maximus.

Table 3. Results of the Two-Way Repeated Measures ANOVA for Each of the Three Effects (Club x Swing Phase Interaction, Club and Swing Phase) by Muscle Laterality

muscle	side	club x swing phase interaction				club				swing phase			
		m	n	*F*	*p*	m	n	*F*	*p*	m	n	*F*	*p*
RA	left	1.4	11.4	0.423[a]	0.598	1	8	2.024	0.193	1.8	14.3	6.690[a]	0.011
	right	1.6	13.2	0.568[a]	0.548	1	8	1.906	0.205	1.3	10.7	11.312[a]	0.004
EO	left	4	28	1.424	0.252	1	7	3.402	0.108	4	28	3.710	0.015
	right	1.4	11.1	2.061[a]	0.178	1	8	2.645	0.143	2.1	16.7	7.753[a]	0.004
ES	left	4	32	1.217	0.323	1	8	0.220	0.652	4	32	6.166	0.001
	right	4	32	1.185	0.336	1	8	4.146	0.760	4	32	9.329	<0.001
GM	left	1.4	9.9	1.041[a]	0.362	1	7	1.968	0.203	1.7	12.1	18.533[a]	<0.001
	right	2	28	1.922	0.135	1	7	4.964	0.061	4	28	12.468	<0.001

Legend: RA – rectus abdominis, EO – external abdominal oblique, ES – erector spinae, GM – gluteus maximus; m – degrees of freedom for the numerator (effect); n – degrees of freedom for the denominator (error); *F* – value of the *F*-ratio; *p* – *p*-value.

[a] Mauchly's test indicated that the assumption of sphericity had been violated, therefore degrees of freedom were corrected

DISCUSSION

The aim of this study is to compare and describe the EMG patterns of trunk muscles in the average golfer during the different phases of the golf swing performed with a short iron (pitching wedge) and a long iron (4-iron).

According to Egret et al.[11] the kinematics and club head speed are different according to the used club, but in the average golfer no club effect on the EMG activity of trunk muscles was found. Okuda et al.[15] stated that the trunk horizontal rotation occurred significantly later in low skilled golfers in the middle of the backswing. So, we can consider the hypothesis that there may be differences in the time activation patterns of the trunk muscles by using different clubs.

During the Backswing, the motor system creates amplitude and stretches the trunk muscles to facilitate their action in the Forward Swing and Acceleration[7,8]. The end of the Backswing is usually the phase in which the golfers reported low back pain due to trunk over-rotation[2], as Bulbulian et al.[8] observed in highly skilled golfers. Although many injuries are often described as occurring at the end of the Backswing[2], there is no evidence of strong muscular activation.

The main tendencies and the values presented in this study were similar to the findings of previous research concerning muscle activation during the Backswing[6,7,9,12]. The RA and GM were the muscles that presented lower levels of EMG activity with mean values under 15% EMG_{MAX} while the EO muscles showed moderate activity levels (23-40% EMG_{MAX}). The EMG activity during this phase was similar with the two clubs. Based on our results, for recreational golfers, the Backswing phase does not demand high activity in trunk muscles.

Since the kinematics of the Backswing includes right trunk rotation followed by trunk hyperextension, left EO (29-30% EMG_{MAX}) and right ES (20-21% EMG_{MAX}) are of major importance. Thus, the coordination and balance between these muscles might be associated with low back pain injuries. When comparing high and low handicap golfers, the latter ones showed higher activity on left EO (22% EMG_{MAX}) than on right EO (17% EMG_{MAX}) and similar activity on right ES (29% EMG_{MAX}) but no statistical differences were found[16]. This could be related to a less efficient swing technique by the high handicap golfers or a smaller sample size. The Forward Swing and the Acceleration were the phases where all studied muscles developed their maximum activation level. The majority of the muscles reached their peak during the Forward Swing, contributing to a powerful trunk rotation. The higher activation was found in the trunk rotators to the left; i.e., the right EO, as would be expected based on trunk rotation biomechanics. However, as stated by Pink et al.[7], right ES is of major importance during this phase by counteracting gravity. Results from other studies also reported lower right EO activity in low handicap golfers[9,16]. So, the values found for the right EO (59-67% EMG_{MAX}) correspond with literature[6,7]. The right GM demonstrated strong activation that could possibly be explained by the right hip extension and the weight transfer to the left. However, the values registered for this muscle (62-72% EMG_{MAX}) were lower than the results found by Bechler et al.[12] for the hip extensor muscles during this phase (nearly 100%). During the Forward Swing, the 4-iron club demonstrated a non-significant increase of 10% EMG_{MAX} in this muscle. The RA muscle presented moderate EMG activation (23-42% EMG_{MAX}) as previously reported by Watkins et al.[6]. An activity level between 27-38% EMG_{MAX} was detected in the ES muscle and was similar to the results found for left ES by other researchers[6,7]. However, these were considerably lower than the levels of 75% and 55% EMG_{MAX} found, for the right ES, by Pink et al.[7] and Watkins et al.[6], respectively. A possible explanation is the different handicap of the subjects under investigation. The level of activation of the ES muscle is dependent on the amplitude of the

Backswing, as stated by Bulbulian et al.[8], and is usually higher in low-handicap golfers. Recreational golfers exhibit less left side bending in the downswing[2] maybe due to a less efficient technique. Consequently, when comparing golfers, the recreational golfers tend to have lower levels of activity of activity in the ES, especially in what the differences between sides is concerned. This might contribute to low back pain injury, the most usual injury area in these players[2].

In the Acceleration phase, high values were found for the left GM (51-67% EMG_{MAX}) and were very close to the ones found by Bechler et al.[12]. This high activation level could be related to lead hip extension. The RA was the muscle that presented the lowest level of activation (17-19% EMG_{MAX}) during this phase. The ES presented moderate levels of activity (26-41% EMG_{MAX}), but showed lower levels (38-58% EMG_{MAX}) compared to other studies[6,7]. The tendency for a higher activity in the left ES found in this study is similar to Watkins et al.[6] and Aggarwal et al.[16], but contradicts the study of Pink et al.[7], Grimshaw and Burden[5] and Cole and Grimshaw[9]. This could be related to differences in the study groups (e.g., professional and recreational golfers), to breaking the golf swing down into fewer phases or points in time, or to differences in signal processing (i.e., band pass filters). Therefore, in this phase, when compared with professional golfers recreational golfers tend to have a higher activation in the left ES than in the right ES. The right EO showed high activation levels (42-63% EMG_{MAX}). The muscular activation difference between clubs was particularly relevant for the right EO that presented increases of 20% EMG_{MAX}. The degree of variability between subjects probably explains the absence of statistically significant differences. High standard deviations of EMG amplitude parameters are commonly encountered in EMG studies[6,8,17,18].

In the Early Follow-Through, the trunk rotation is decelerated and the energy dissipated. The EO, from both sides, were strongly recruited during this phase. The mean activation levels ranged 24% to 50% EMG_{MAX} which were similar to Pink et al.[7] and Watkins et al.[6], and revealed an increase of 10% EMG_{MAX} with 4-iron club similar with the Forward Swing phase. The ES and RA presented low activation levels (13-22% EMG_{MAX}) but were lower than the values (20-40% EMG_{MAX}) reported by Pink et al.[7] and Watkins et al.[6]. This difference in the ES could be related to a deep left side bending in the Backswing. Bulbulian et al.[8] found that a shorter Backswing exhibits a higher activity in the left lumbar muscle. Other possible explanations include the EMG normalization procedures suggested by Konrad[13] and Hermens et al.[19] to evaluate MVC.

The Late Follow-Through is the final stage of the golf swing and it mainly consists of a spinal rotation. The muscle that showed higher levels of activation during this phase was the right EO, with mean values ranging from 35 to 70% EMG_{MAX}. These values correspond to previous literature[6,7]. The final trunk rotation is the most cited reason for the activation of these muscles. The RA (8-13% EMG_{MAX}) and the ES (17-18% EMG_{MAX}) from both sides presented low activity during this phase, as also reported by Watkins et al.[6]. However, Pink et al.[7] observed higher activation levels for the ES. A low level of activation was also observed in the GM (12-22% EMG_{MAX}) of both sides. This phase is also a very demanding phase, mainly for the trunk rotators, and is commonly associated with the occurrence of injuries either in skilled players or in recreational players[2].

Although there is evidence of low back pain injuries in both high and low handicap golfers, the injury mechanism might be different. The recreational golfers' injuries seem to be related to poor swing technique or poor warming up and physical condition[2].

The results shown might help coaches and clinicians to build specific intervention programmes in order to minimize or prevent the most common golf injury – low back pain.

As a result, those professionals should be concerned with player's physical condition, namely of the trunk muscles.

When comparing clubs no statistical differences were found, perhaps due to the high interindividual variability combined with a small sample size. This is a limitation of the present study. For future studies, we suggest that the subjects' characteristics (age, experience and handicap) should be more carefully considered using a more homogeneous or larger sample.

CONCLUSION

The results showed that, for the average golfers, no differences in the activation level of trunk muscles were observed between the swing performed with two different clubs, the pitching wedge and the 4-iron.

The Forward Swing and the Acceleration were the phases where all studied muscles developed their maximum activation level. The majority of the muscles reached their peak during the Forward Swing, contributing to a powerful trunk rotation. The muscles that presented higher activation were the trunk rotators to the left; i.e., the right EO, and the GM from both sides.

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Capítulo 6

Estudo IV

Análise eletromiográfica dos músculos do membro inferior durante o swing do golfe realizado com três tacos diferentes

Artigo Submetido

Marta, S., Silva, L., Vaz, J., Castro, M. A., Reinaldo, G., & Pezarat-Correia, P. (2013). EMG analysis of the lower limb muscles during the golf swing performed with three different clubs. *Journal of Sports Science*.

EMG analysis of lower limb muscles during the golf swing performed with three different clubs

Abstract

The aim of this study was to compare the EMG patterns of the lower limb muscles throughout the golf swing, performed with three different clubs, and also to describe the activity patterns in the average golfer.

Fourteen golfers performed eight swings using, randomly, three different clubs: pitching wedge, 7-iron and 4-iron. Surface electromyography (EMG) was recorded from lower limb muscles of both sides: tibialis anterior (TA), peroneus longus (PL), gastrocnemius medialis (GeM), gastrocnemius lateralis (GeL), biceps femoris (BF), semitendinosus (ST), gluteus maximus (GM), vastus medialis (VM), rectus femoris (RF) and vastus lateralis (VL). 3D high-speed video analysis was used to determine the golf swing phases. According to data, the highest muscle activation levels were during the forward swing and acceleration phases. In average handicap golfers the highest mean activation regarding the maximal EMG (EMG_{MAX}) was found in the right ST (65-73% EMG_{MAX}) and in the right BF (68-76% EMG_{MAX}). Significant differences between the pitching wedge and the 4-iron club were found in the activation level of the left semitendinosus, right tibialis anterior, right peroneus longus, right vastus medialis, right rectus femuris and right gastrocnemius muscles. The lower limb muscles showed, in most cases and phases, higher mean values of EMG activation when golfers performed with a 4-iron club.

Introduction

The golf swing and its effect are conditioned by muscle recruiting (Hume, Keogh, & Reid, 2005). During the golf swing the whole body must move coordinately in order to transfer power and the desired trajectory to the ball (McHardy & Pollard, 2005). Poor swing mechanics are frequently associated with injury (Bayes & Wadsworth, 2009). Most of the golf swing EMG studies focus on trunk movement (Bulbulian et al., 2001; Cole & Grimshaw, 2008; Horton et al., 2001; Pink, Perry, & Jobe, 1993; Silva et al., 2013; Watkins, Uppal, Perry, Pink, & Dinsay, 1996), since most prevalent injuries occur in lower back (Cabri, Sousa, Kots, & Barreiros, 2009). It is also possible to find in literature some EMG research performed with upper limb muscles, mainly proximal muscles acting on the scapula (Kao, Pink, Jobe, & Perry, 1995) and gleno-humeral joint (Jobe, Moynes, & Antonelli, 1986; Jobe, Perry, & Pink, 1989; Pink, Jobe, & Perry, 1990).

However, it is known that low back pain might be related with inefficient lower limb biomechanics (Pink at al., 1993). In fact, as stated be McHardy, Pollard and Luo (2006), lower limbs experience high forces, specially the knee, but there is a lack of EMG investigation about lower limbs muscles (Marta, Silva, Castro, Pezarat-Correia, & Cabri, 2012). Only Bechler, Jobe, Pink, Perry, and Ruwe (1995) have published a study specifically concerned with lower limb muscle activity. However, this study monitored only proximal muscles acting on the hip and knee joints, and recording EMG using the single-needle method. As main findings, Bechler et al. (1995) reported that the gluteus maximus was the most active muscle of the lower limb and that higher activity was found in the trail leg during the takeaway and forward swing whereas in the lead leg it was observed during the acceleration and follow-through. In a study about trunk muscles activation during the golf swing, Watkins et al. (1996) also monitored the gluteus maximus muscle with results similar to the study of Bechler et al. (1995). The studies performed by Bechler et al. (1995) and Watkins et al. (1996) focused on the professional and lower handicap (<5) participants, respectably.

The need for further studies on golfers of different skill levels and swing types, to determine if there are any substantial differences between these subgroups, was empathised by McHardy and Pollard (2005). According to Cheetman, Martin, Mottram, and St Laurent (2001) the legs and hips initiate the development club head speed with rapid rotation of the pelvis, during the forward swing and acceleration phases. In addiction, Egret, Vincent, Weber, Dujardin, and Chollet (2003) reported kinematic and club head speed differences by using different clubs, so we can consider the possibility that muscular demands of the lower limbs are affected by the use of different club types. It is also important to point out that, to the best of our knowledge, there are no available studies comparing lower limb muscle activity with the use of different clubs. Since the lower limb region is one of the frequent injured regions in golf players (McHardy et al., 2006) it would be important to investigate neuromuscular mechanisms related to weight transfer between lower limbs during the swing.

In this report, we test the hypothesis of differences in lower limb muscles activations between clubs. Therefore, the objective of the present work is to compare the EMG patterns of lower limb muscles during the different phases of the golf swing performed with a long iron (4-iron), an intermediate iron (7-iron) and a short iron (pitching wedge).

Additionally, the neuromuscular patterns of the lower limb muscles will be described, in each phase, on the average golfer. This study offers a new approach to the description of the leg muscles activity during the golf swing.

Methods

Participants and task

Fourteen volunteers' right-handed male golfers participated in this study. The sample consisted of recreational golfers, with a mean age of 51.1±9.1 years (range 39-64) and mean handicap of 14.5±1.5 (range 11.9-17) (Table 1). The participants were instructed to perform eight shots with each club, an accuracy shot with the pitching wedge (<100m), an intermediate shot (between 100m and 150m) with a 7-iron and a long distance shot with the 4-iron (>150m), in random sequence of four trials. Participants were encouraged to take into consideration their average distances with the three clubs, making each shot as real as possible. The clubs had graphite shafts of standard length. The participants hit a regular golf ball to a target placed 6m away using their own clubs, glove and shoes on an artificial turf golf mat with high shock absorption characteristics.

The participants showed no limitation for golf practice (i.e. injuries) and accepted to complete the investigation protocol. All procedures and objectives of the study were explained to the participants who signed a written informed consent. The Research Ethics Committee of the Faculdade de Motricidade Humana, Universidade de Lisboa approved the study that was in conformity with the Helsinki Declaration of 1975 and 2008.

General procedures

After the explanation of study purposes and collection steps, the subjects answered a brief questionnaire about subject characteristics. The skin was prepared and electrodes were placed. Then followed a warming up period of approximately five minutes. Later, EMGs of Maximal Voluntary Isometric Contraction (EMG_{MAX}) were collected. Reflective marks were placed (Horton et al., 2001) for video analysis and synchronization procedures were performed. Before experimental procedures, all subjects were allowed to perform some swing trials for a better adaptation to the task and started when they considered to be ready.

Video data recording, processing and analysis

Video analysis was used for identification of golf swing phases. For kinematic analysis a three dimensions SIMI Motion 3D system (SIMI Reality Motion Systems GmbH, Unterschleissheim, Germany) was used. The golf swing was recorded with five high-speed cameras Basler A602fc (Basler Vision Technologies, Ahrensburg, Germany) at 100 Hz. The cameras were placed at anterior, posterior and superior oblique, adjusted for the best 3D reconstruction. Two markers were placed on the individuals' clubs according to Horton et al. (2001).

Video data was synchronized with EMG data to divide the golf swing into five phases: (1) the Backswing – from the address to top of the swing; (2) the Forward Swing – from the top of the swing to the horizontal club (early part of Downswing); (3) the Acceleration – from the horizontal club to impact (late part of Downswing); (4) the Early Follow-Through – from the impact to horizontal club; (5) the Late Follow-Through – from the horizontal club to the completion of the swing.

EMG data recording, processing and analysis

Skin was prepared by means of hair removal, abrasion and alcohol cleaning to collect the electromyographic signals with active surface electrodes (Al/AgCl, rectangular shape 30 x 22 mm) the AMBU® BlueSensor N (AMBU, Ballerup, Denmark) and telemetric equipment bioPLUX® research 2010 (PLUX, Lisbon, Portugal) with Bluetooth connectivity in both sides of the ten studied muscles. Sensors amplified the EMG signals with a bandpass (10-500 Hz), common-mode rejection ratio (CMRR) of 110 dB and input impedance greater than 100 M**Ω**. All EMG data were sampled at 1000 Hz, digitally filtered (10-490 Hz), full wave rectified, smoothed through a low-pass filter (12 Hz, fourth-order Butterworth digital filter), and amplitude normalized by using the peak 100-ms EMG signal during EMG_{MAX}, as reference. The average value of EMG signal was calculated during each phase of the golf swing for each repetition, condition and subject. EMG processing was performed using a routine by MATLAB® software V.R2013a (The Mathworks Inc., Natick Massachusetts, USA). To guarantee the quality of the signals, visual inspection was made by experienced researchers prior to EMG processing.

The electrodes were aligned with muscle fibers orientation with a center-to-center distance of 22 mm, at the most prominent part of the muscle bellies taking into account the following references (Hermens et al., 1999): Tibialis Anterior (TA) - At 1/3 on the line between the tip of the fibula and the tip of the medial malleoulus; Peroneus Longus (PL) -

At 25% on the line between the tip of the head of the fibula to the tip of the lateral malleolus; Gastrocnemius Medialis (GeM) - In the most prominent bulge of the muscle; Gastrocnemius Lateralis (GeL) - At 1/3 of the line between the head of the fibula and the heel; Gluteus Maximus (GM) - At 50% on the line between the sacral vertebrae and the greater trochanter just in the middle of the buttocks well above the visible bulge of the greater trochanter; Vastus Medialis (VM) - At 80% on the line between the anterior spina iliaca superior and the joint space in front of the anterior border of the medial ligament; Rectus Femuris (RF) - At 50% on the line from the anterior spina iliaca superior to the superior part of the patella; Vastus Lateralis (VL) - At 2/3 on the line from the anterior spina iliaca superior to the lateral side of the patella; Semitendinosus (ST) - At 50% on the line between the ischial tuberosity and the medial epicondyle of the tíbia; Biceps Femoris (BF) - At 50% on the line between the ischial tuberosity and the lateral epicondyle of the tibia. The ground electrode was placed over the manubrium sterni (Horton et al., 2001). In order to decrease the impedance of the interface between skin and electrode, the skin was prepared by removing hair through skin abrasion and by cleaning it with alcohol.

Two isometric repetitions of 3 to 4 seconds for determination of the EMG_{MAX} were performed by each muscle for EMG signal normalization with the following protocols: TA – Support the leg just above the ankle joint with the ankle joint in dorsiflexion and the foot inversion without extension of the great toe, and apply pressure against the medial side, dorsal surface of the foot in the direction of plantar flexion of the ankle joint and eversion of the foot; PL – Support the leg just above the ankle joint and everse the foot with plantar flexion of the ankle joint while applying pressure against the lateral border and sole of the foot, in the direction of inversion of the foot and dorsiflexion of the ankle joint; GeM and GeL – In single limb stance, plantar flexion of the foot with emphasis on pulling the heel upward more than pushing the forefoot downward; for maximal pressure in this position it is necessary to apply pressure against the forefoot as well as against the calcaneus, GM – In prone position lift the complete leg (laterally rotated) against manual resistance; RF, VM and VL – Extended knee without rotating the thigh while applying pressure against the leg above the ankle towards flexion; BF and ST – Press against the leg proximal to the ankle towards knee extension.

Participants were verbally encouraged during the maximal isometric efforts and, to avoid fatigue, 2 minutes rest was allowed between repetitions. EMG normalizing procedure was consistent with procedures described by Konrad (2005) and Hermens et al. (1999) to evaluate MVC.

Statistical analysis

Data were processed in IBM SPSS Statistics 21.0 (IBM Corporation, New York, USA) software. Descriptive statistics were reported as mean±SD of % EMG_{MAX}. A two-way repeated measures ANOVA was conducted to explore the impact of the three clubs and phases, on each muscle from both sides and the univariate analysis was extended to each phase. Besides the Central Limit Theorem data normality distribution was guaranteed by root square transformation. Statistical significances between measures were assessed by the Greenhouse-Geisser when the sphericity was violated. Pairwise comparisons were performed with Bonferroni test. The significance level was set at $p<.050$.

Results

Figure 1, Figure 2 and Figure 3 show profile plots of the average percentage values of EMG_{MAX} of each muscle in different phases for the three clubs.

Table 2 presents the results of the two-way repeated measures ANOVA by muscle laterality for the three effects (club, swing phase and club x swing phase).

Comparison between clubs (pitching wedge, 7-iron and 4-iron)

The intensity activation patterns between the three clubs were similar. There were found significant differences between the clubs, especially between the pitching wedge and the 4-iron club, on muscles from the right side. The right VM, right TA, right PL, right GeM and right GeL showed significant differences between the pitching wedge and the 4-iron, especially during the Forward Swing and Acceleration phases ($p<.012$). The right RF and left ST showed significant differences between the pitching wedge and the other two clubs ($p<.001$).

Comparison between phases

All muscles showed low or medium levels of activity (6-31% EMG_{MAX}) during the Backswing phase, in three clubs. The gastrocnemius from both sides, right TA, right PL, right BF, right ST, right GM muscles reached the peak in the Forward Swing (16-73% EMG_{MAX}), while in the left TA, left PL, left BF, left ST, left GM, left VM, left RF, and left VL peak occurred in the Acceleration (14-58% EMG_{MAX}). In the Early Follow-Through and Late Follow-Through all muscles decreased activity (5-38% EMG_{MAX}). All the muscles showed significant differences between the phases, especially during the peak and the other phases ($p<.001$).

Discussion and implications

This study compares and describes the EMG patterns of lower limb muscles in the recreational golfer during the different phases of the golf swing performed with three different clubs: a short iron (pitching wedge), an intermediate iron (7-iron) and a long iron (4-iron). This hypothesis was formulated on the grounds of the significant differences between the kinematic and club head speed in different clubs (Egret et al., 2003). Subsequently, differences in activation patterns of the lower limb muscles can occur by using different clubs. Additionally, the neuromuscular patterns of the leg muscles are described.

In the address, the ball position and the stance are associated with the club used and the knees are flexed at 20º-25º (Hume at al., 2005). A swing performed with a minor club (pitching wedge) starts with the ball at centre stance, and becomes further from it (to the left on a right handed golfer), as the number of the club is lower and the shaft length increases. This difference in the starting position can lead to the significant higher levels of activity in the right TA in the 4-iron club ($p<.001$) as more weight is supported on the trail foot. The intensity activations patterns of the studied muscles are identical to the ones found by Bechler et al. (1995) but with lower values. This difference of the mean values can be related to some methodological difference in the collection (fine wire), and processing of EMG data and in the use of a different club (driver club). The muscles acting on the right hip and knee showed, in general, a higher level of activity than those acting on the left side, as reported by Bechler et al. (1995) but no significant differences were found between clubs for these muscles in the backswing. The body weight is located on the right side, as the body finishes rotating to the right side. The right ST, BF, GeL and GeM exhibited medium level of activity to flex the knee in the address position and to medial rotate, preventing the knee extension. The medium activity in the right PL aids to keep this side static on the ground during this phase of the swing. The three clubs showed identical levels of activity during the backswing.

During the Forward Swing the club begins the controlled fall and the pelvis starts to rotate to the target-side (Burden, Grimshaw, & Wallace, 1998). High levels of activity of the right BF, right GM and right ST (49-76% EMG_{MAX}) helped to extend the right hip while the right knee extensors showed lower muscle activity (10-17% EMG_{MAX}), especially in the 4-iron club. The GeM and GeL from both sides reached their peak with medium to high levels of activity (29-46% EMG_{MAX}) helping the knees to stay flex and probably to help the positioning of the target-side knee over the target-side foot. In the left side the VM, RF and VL peaked in high levels of activity (39-58% EMG_{MAX}) probably to help the pelvis rotate and transfer the body weight to the target-side, but no significant difference were found between clubs (p>.050).

As the swing enters in the Acceleration phase, the left core hip extensors (GM, BF and ST) become more active (36-54% EMG_{MAX}) providing a fulcrum (Vad et al., 2004), which manages the pelvis rotation and keeps the knee over the foot, especially in the 7-iron and 4-irion clubs. The left TA and left PL reached their peak helping to drive the golfer into the ground with 28-29% EMG_{MAX} and 38-42% EMG_{MAX}, respectably, but no significant differences were found between clubs (p>.050). The right VM, RF and VL also reached their peak (19-38% EMG_{MAX}) with significant differences between the pitching wedge and the 4-iron club, possibly to help pelvis rotation, extend the knee to supply power to the golf club (Bechler et al., 1995).

In the Early Follow-Through phase the body decelerates as the left BF, left ST, left VL and left VM decreased their activity to medium levels of activity (35-54% EMG_{MAX}). The left and right PL muscles slightly decreased the levels of activity (25-31% EMG_{MAX}) presumably to maintain both feet on the ground. Therefore, the lower limbs stabilize the pelvis so the abdominal oblique can be activated to decrease the trunk rotation (Pink et al., 1993). During this phase the three clubs showed identical levels of activity, except in the right PL between the pitching wedge (33% EMG_{MAX}) and the 4-iron (39% EMG_{MAX}) club with a difference of 6% EMG_{MAX}.

During the Late Follow-Through the right PL, GeM and GeL slightly increased its activity to medium levels of activity (25-36% EMG_{MAX}) to stabilize the right leg and ankle in the position. The left ST kept the anterior levels of activity to help decrease the pelvis rotation and the left PL to support the foot on the ground. In this phase the three clubs showed identical levels of activity.

The two portions of the right triceps surae, the GeL and the GeM showed significantly higher levels of activity in the 4-iron club during the Forward Swing, Acceleration and Early Follow-Through phases. These levels of activity can be related with the higher shaft length and the ball position (two balls to the left from the center stance) and can delay the weight transfer to the left side. The right TA and right PL higher significant activations levels in the 4-irion can be connected with the body balance reflex and lower swing skill technique. The upper trunk-pelvis rotation relation (the X-factor) during the Backswing phase and the hub path geometry described by the club in the

Acceleration phase can unbalance the swing with significant levels in the right TA and increase significantly the activation levels of the right PL in the Forward Swing and Early Follow-Through phases for the 4-iron club. The right VM and RF significantly higher levels of activity in the 4-iron can be linked with a knee protection and rotation to the final position during the Forward Swing, Acceleration, Early Follow-Through and Late Follow-Through phases. So, a golfer with weak knees can be more predisposed to knee injuries when swinging with longer irons. The left ST was the only muscle from the left side that showed lower significant levels of activity and only in the Acceleration phase but between the pitching wedge and the other studied clubs. Therefore, long and intermediate clubs can increase the hip extension assisting the stabilization of the pelvis and the medial rotation of the knee by positioning the knee over the target-foot. This pelvic tilt can be associated presumably with golfers low back pain injuries.

Researchers reported (Cabri et al., 2009; Lindsay, Horton, & Vandervoort, 2000; McHardy et al., 2006) that 11% of the golfers have injuries on the lower limbs (on the knee from overuse and on the ankle by simple trauma accident). At the end of the Acceleration and Follow-Through phases the left knee supports a peak force (McHardy et al., 2006) from medial rotation, posterior and varus forces that can aggravate the knee condition. Some studies reported patellar fractures (Isaacs & Schreiber, 1992) and tibial stress fractures (Gregori, 1994). The balanced activation levels of the VM, VL and RF during each phase can help to stabilize the knee and support the forces applied to it. An unbalanced knee can trigger an overuse injury. The mean peak forces and moments are not related to the golfer skill level but to the swing pattern characteristics (Gatt, Pavol, Parker, & Grabiner, 1998), so some golfers that have predisposing factors – like bone mal-alignments and reduced muscle force ratio – or poor swing technique (Batt, 1992) can be more susceptible to suffer from knee injuries, which can affect especially novice golfers (Hume et al., 2005).

Optimal intermuscular coordination can conduct to a better kinetics transfer starting on the lower limbs and pelvis and then transporting it to the trunk, arm and finally to the head of the club. The ground-up appears to be the first link in the chain of energy transfer through the usage of the TA, PL, GeL and GeM activation levels on the right side during the Forward Swing and Acceleration phases, while the BF, ST, GM muscles are considered vital to produce and transfer force supporting the golf swing (Loock, Grace, & Semple, 2013). This muscular event is specially seen with the high activity in the 4-iron, probably due the higher shaft of this club.

The lower limbs support a greater torque during a swing (Gatt et al., 1998) but lower limbs injuries are less prevalent in golfers. On other side recreational golfers' injuries seem to be related to poor swing technique or poor warming up and physical condition (Cabri et al., 2009). The results shown might help coaches and clinicians to build specific intervention programmes in order to minimize or prevent injury and support the kinetic transfer from the ground to the club. As a result, those professionals should be concerned with player's physical condition of lower limbs muscles, since they support the high activations of the trunk muscles (Pink et al., 1993) by stabilizing the pelvis (Watkins et al., 1996).

The neuromuscular patterns are generally described by the amplitude studies but are limited by the muscle onset and offset and the length of the phase. If a muscle presents low levels of activity for a long time, it could interfere in the phase mean values. In some cases and during some phases, an extremely rapid peak occurs but it is masked by the amplitude studies. Therefore, new studies that integrate the intensity and time parameters should be considered to better understand how the Central Nervous System activates the muscular system during a complex motor skill as the golf swing.

Conclusion

The neuromuscular patterns of the lower limb muscles during the different phases of the golf swing were characterized on the average golfer. The most active phases were the Forward Swing and the Acceleration where all studied muscles developed their maximum activation level. The right posterior and left anterior hip muscles reached their peak during the Forward Swing, while the right anterior and left posterior hip muscles peaked in the Acceleration phase, contributing to a pelvis rotation. The leg muscles, right tibialis anterior, right peroneus longus and gastrocnemius (medialis and lateralis) peaked during the Forward Swing whilst the left tibialis anterior and left peroneus longus reached their maximum in the Acceleration phase. The muscles that presented higher activation levels were the right biceps femoris and right semitendinosus.

The results also showed that, for the average golfers, significant differences in the activation level of the left semitendinosus, right tibialis anterior, right peroneus longus, right vastus medialis, right rectus femuris and right gastrocnemius muscles were observed between the pitching wedge and the 4-iron club. More specifically the lower limb muscles showed, in most cases and phases, higher mean values of EMG activation when golfers swung with a 4-iron club.

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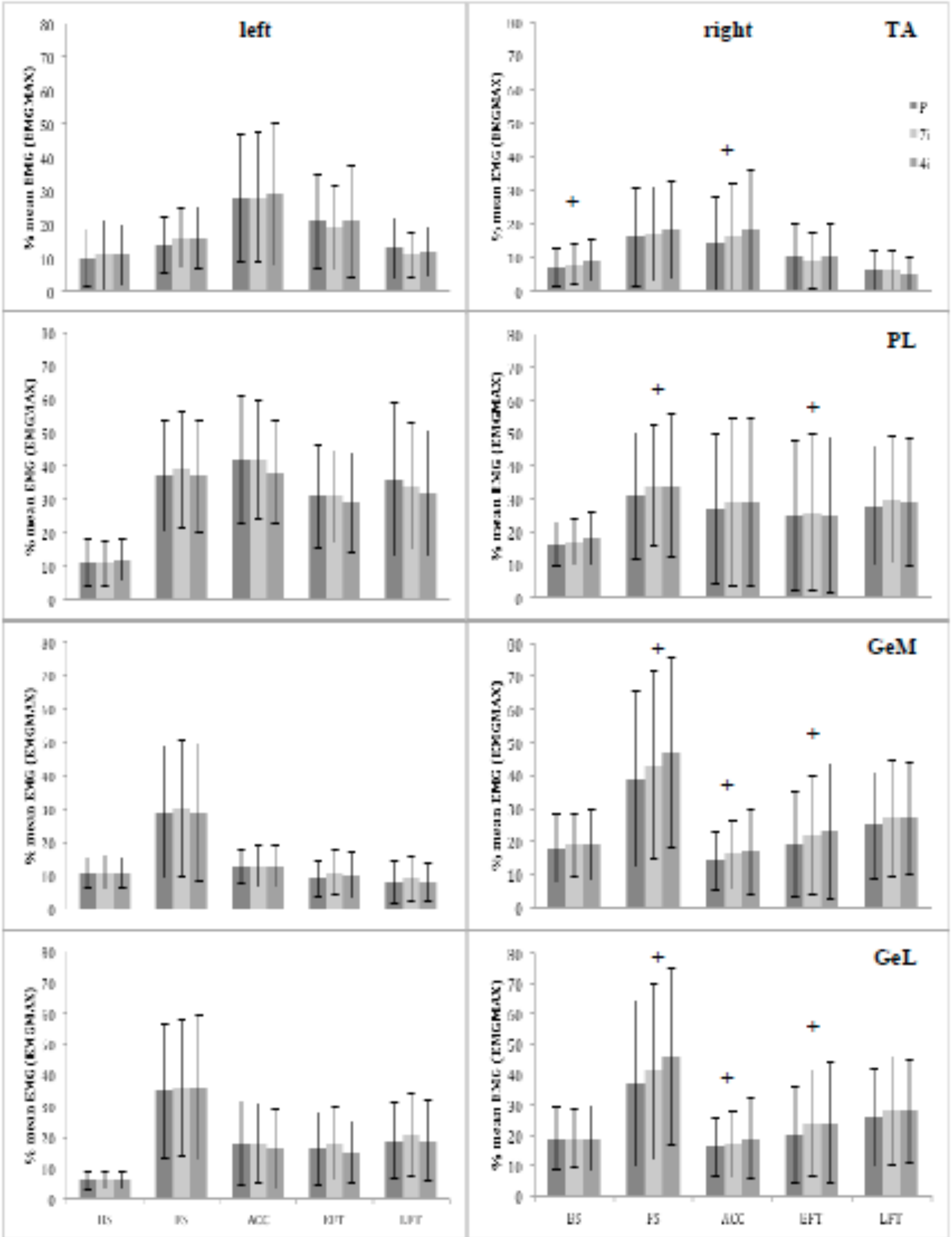

Figure 2 - Average percentage value of normalized EMG (EMG_{MAX}) from the leg by muscle laterality on each phase by club.
Legend: TA – tibialis anterior; PL – peroneus longus; GeM – gastrocnemius medialis; GeL – gastrocnemius lateralis; BS – Backswing; FS – Forward Swing; ACC – Acceleration; EFT – Early Follow-Through; LFT – Late Follow-Through; P – pitching wedge; 7i – 7-iron; 4i – 4-iron, + – significant diferences between the pitching wedge and the 4-iron, # – significant diferences between the pitching wedge and the 7-iron.

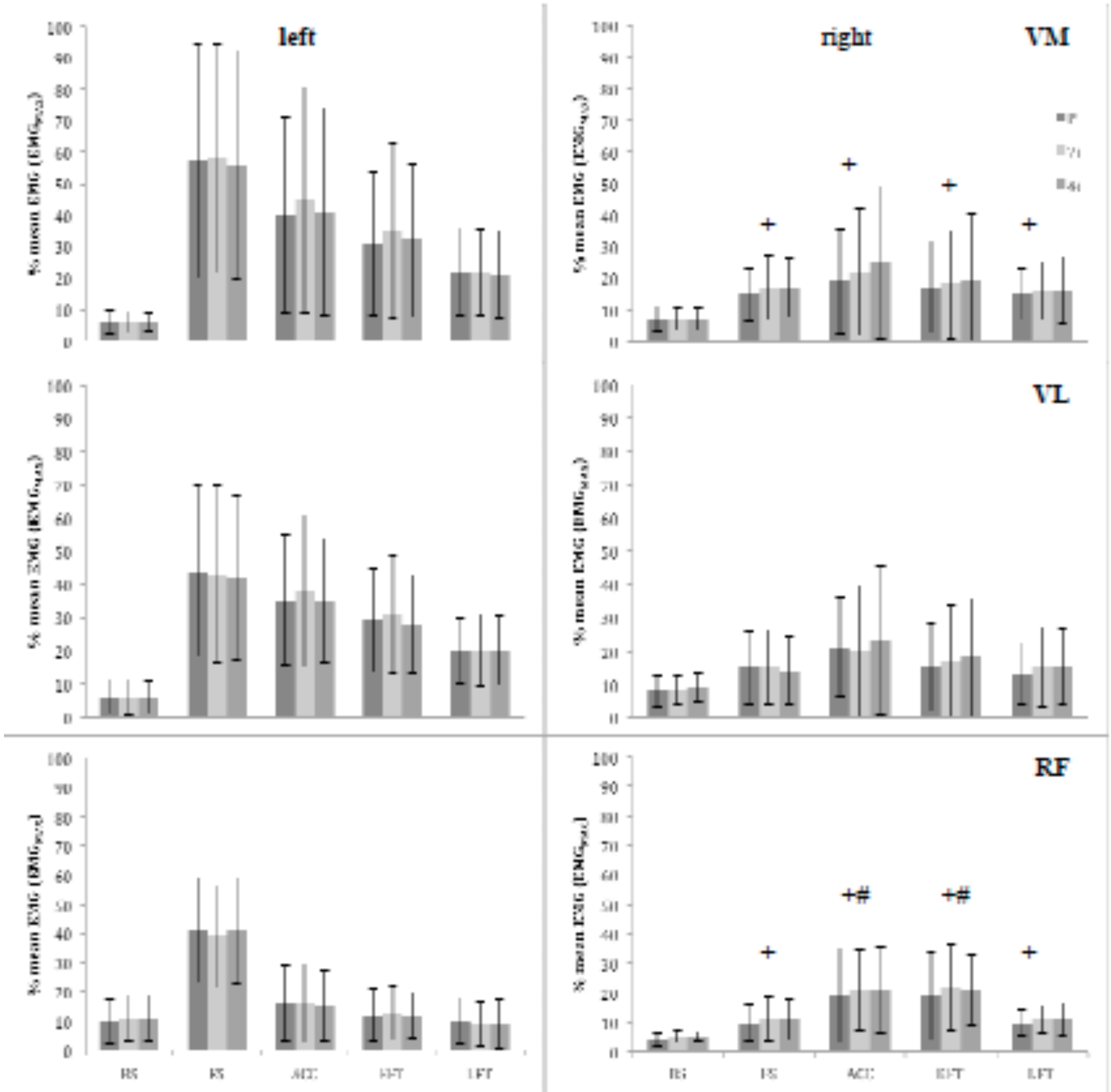

Figure 3 - Average percentage value of normalized EMG (EMG_{MAX}) from the anterior hip by muscle laterality on each phase by club.
Legend: VM – vastus medialis; VL – vastus lateralis; RF – rectus femoris; BS – Backswing; FS – Forward Swing; ACC – Acceleration; EFT – Early Follow-Through; LFT – Late Follow-Through; P – pitching wedge; 7i – 7-iron; 4i – 4-iron, + – significant diferences between the pitching wedge and the 4-iron, # – significant diferences between the pitching wedge and the 7-iron.

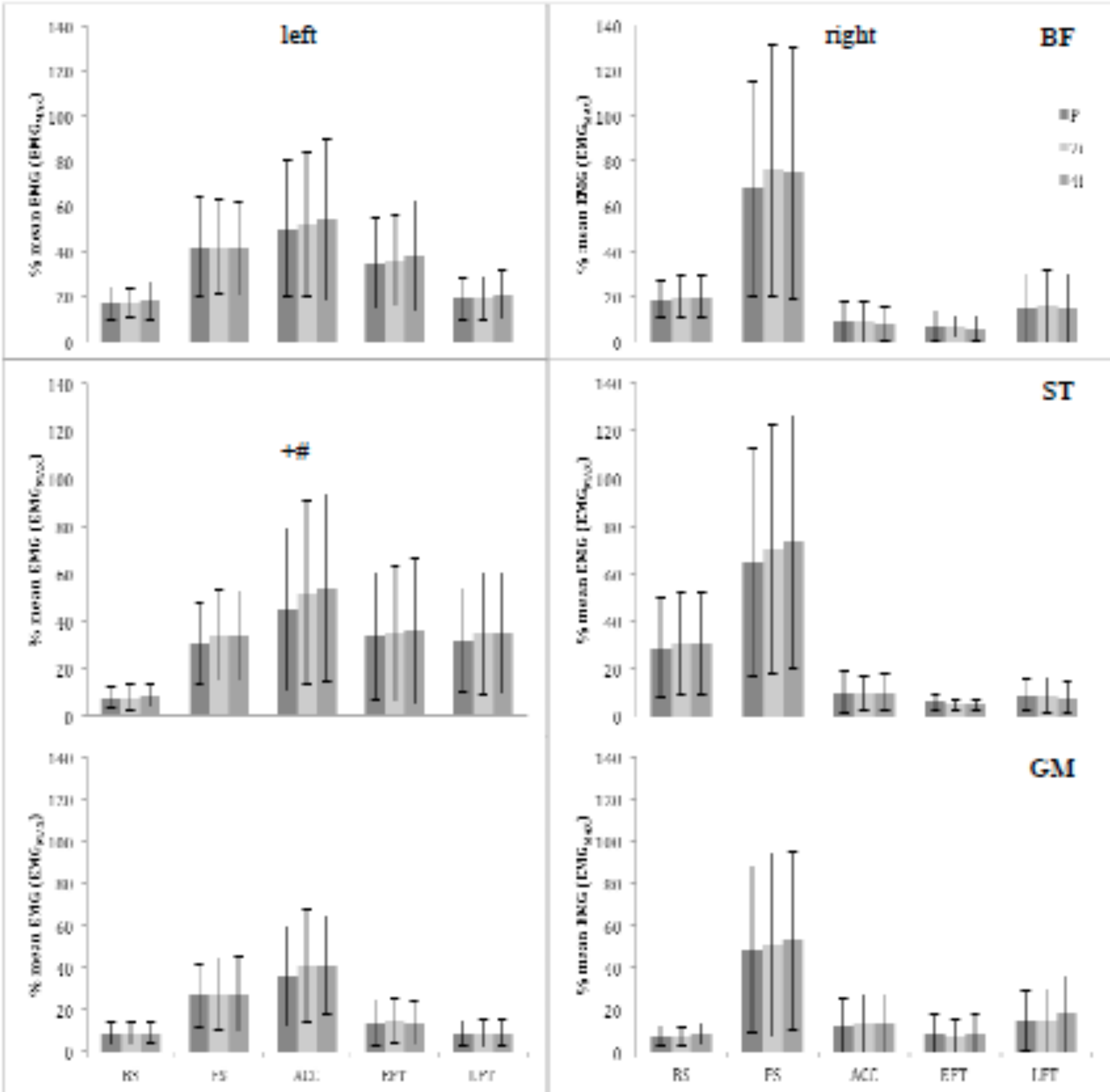

Figure 4 - Average percentage value of normalized EMG (EMG_{MAX}) from the posterior hip by muscle laterality on each phase by club.
Legend: BF – biceps femoris; ST – semitendinosus; GM – gluteus maximus; BS – Backswing; FS – Forward Swing; ACC – Acceleration; EFT – Early Follow-Through; LFT – Late Follow-Through; P – pitching wedge; 7i – 7-iron; 4i – 4-iron, + – significant diferences between the pitching wedge and the 4-iron, # – significant diferences between the pitching wedge and the 7-iron.

Table 1 - Subjects characteristics (n=14)

Characteristics	mean ± SD	range
Handicap	14.5 ± 1.5	(11.9 – 17.0)
Age (yr)	51.1 ± 9.1	(39.0 – 64.0)
Height (m)	1.76 ± 0.1	(1.65 – 1.82)
Body Mass (kg)	80.9 ± 8.8	(68.0 – 90.5)
Experience (yr)	9.9 ± 4.9	(5.0 – 25.0)

Table 2 – Results of the two-way repeated measures ANOVA for each of the three interaction (club x swing phase interaction, club and swing phase) by muscle laterality

muscle	side	club					swing phase					club x swing phase interaction				
		m	*n*	*F*	*p*	*op*	*m*	*n*	*F*	*p*	*op*	*m*	*n*	*F*	*p*	*op*
TA	left	2	202	.808	.447	.187	**2.786**	**281.395**	**33.776**	**.000**	**1.000**	6.583	664.857	2.053	.051	.776
	right	**1.726**	**165.695**	**7.101**	**.002**	**.897**	**2.839**	**272.582**	**47.419**	**.000**	**1.000**	4.616	443.096	2.282	.051	.712
PL	left	2	200	1.220	.297	.264	**3.166**	**316.638**	**115.585**	**.000**	**1.000**	6.161	616.113	1.251	.278	.503
	right	**2**	**194**	**8.093**	**.000**	**.956**	**2.528**	**245.248**	**29.164**	**.000**	**1.000**	5.643	547.365	.968	.443	.372
GeM	left	2	186	.803	.449	.186	**2.110**	**196.244**	**101.569**	**.000**	**1.000**	6.776	630.181	.839	.552	.359
	right	**2**	**202**	**8.444**	**.000**	**.963**	**3.100**	**313.135**	**48.983**	**.000**	**1.000**	5.088	513.881	2.729	.018	.828
GeL	left	2	190	.888	.413	.202	**2.838**	**269.581**	**188.968**	**.000**	**1.000**	6.614	628.310	1.247	.277	.522
	right	**2**	**200**	**9.349**	**.000**	**.977**	**2.938**	**293.845**	**37.181**	**.000**	**1.000**	**4.943**	**494.337**	**3.157**	**.008**	**.879**
BF	left	1.771	182.463	2.696	.077	.497	**2.612**	**269.084**	**122.889**	**.000**	**1.000**	6.133	631.729	1.584	.147	.620
	right	2	172	.534	.587	.137	**1.872**	**161.011**	**130.418**	**.000**	**1.000**	5.558	477.984	1.077	.374	.409
ST	left	**2**	**206**	**9.458**	**.000**	**.979**	**2.251**	**231.889**	**138.924**	**.000**	**1.000**	**6.277**	**646.517**	**3.122**	**.004**	**.929**
	right	2	178	3.755	.025	.680	**1.548**	**137.814**	**178.783**	**.000**	**1.000**	5.837	519.523	1.904	.080	.698
GM	left	2	206	2.934	.055	.567	**2.034**	**209.477**	**164.198**	**.000**	**1.000**	5.139	529.330	1.375	.231	.495
	right	2	210	1.191	.306	.259	**2.307**	**242.228**	**118.327**	**.000**	**1.000**	5.992	629.146	.534	.783	.216
VM	left	2	176	.842	.433	.193	**2.486**	**218.736**	**138.967**	**.000**	**1.000**	6.327	556.764	2.148	.043	.785
	right	**1.786**	**173.280**	**8.473**	**.001**	**.949**	**2.335**	**226.515**	**46.264**	**.000**	**1.000**	4.747	460.434	2.574	.028	.780
RF	left	2	164	.114	.892	.067	**2.150**	**176.275**	**115.892**	**.000**	**1.000**	3.996	327.631	.599	.663	.197
	right	**1.619**	**166.719**	**9.220**	**.000**	**.951**	**2.001**	**206.143**	**106.016**	**.000**	**1.000**	4.247	437.407	2.656	.030	.759
VL	left	2	188	.141	.869	.071	**2.352**	**221.131**	**142.007**	**.000**	**1.000**	6.292	591.431	1.578	.147	.625
	right	**1.619**	**168.348**	**5.090**	**.012**	**.754**	**2.354**	**244.812**	**28.467**	**.000**	**1.000**	4.478	465.705	1.950	.093	.623

Legend: TA – Tibialis Anterior. PL – Peroneus Longus. GeM – Gastrocnemius Medialis. GeL – Gastrocnemius Lateralis. BF – Biceps Femoris. ST – Semitendinosus. GM – Gluteus Maximus. VM – Vastus Medialis. RF – Rectus Femoris VL – Vastus Lateralis; m – degrees of freedom for the numerator (effect); n – degrees of freedom for the denominator (error); *F* – value of the *F*-ratio; *p* – *p-value*; *op* – observer power.

Capítulo 7

Estudo V

Análise eletromiográfica dos músculos do membro inferior durante o swing de golfe executado em jogadores de golfe de baixo e alto handicap.

Artigo Submetido

Marta, S., Silva, L., Vaz, J., Castro, M. A., Reinaldo, G., & Pezarat-Correia, P. (2013). Electromyographic analysis of the lower limb muscles in low and high handicap golfers. *European Journal of Sports Science*.

Electromyographic analysis of the lower limb muscles in low and high handicap golfers

Abstract

The aim of this study was to compare the EMG patterns of the lower limb muscles, performed by low and high handicap golfers during a golf swing. Ten golfers (five high skilled and five low skilled) performed eight swings using a 7-iron. Surface electromyography (EMG) was recorded in lower limb muscles of both sides: biceps femoris (BF), semitendinosus (ST), gluteus maximus (GM), vastus medialis (VM), vastus lateralis (VL), rectus femoris (RF), tibialis anterior (TA), peroneus longus (PL), gastrocnemius medialis (GeM) and gastrocnemius lateralis (GeL). The golf swing phases were determined by 3D high-speed video analysis. The forward swing and acceleration were the most active phases showing high muscle activation levels. The highest mean activation regarding the maximal EMG (EMG_{MAX}) was found in the right BF (75 – 94% EMG_{MAX}), right GM (51 – 82% EMG_{MAX}), left PL (46 – 73% EMG_{MAX}) and in the right gastrocnemius (23 – 68% EMG_{MAX}) in the forward swing phase. Between the low and high handicap golfers, significant differences were found in the left lower limb, the right gastrocnemius and the average swing duration phases.

Introduction

Golf has become a worldwide popular sport (Farrally et al., 2003) with new players and golf courses. With this increased accessibility and participation more musculoskeletal injuries have been reported (Cabri, Sousa, Kots & Barreiros, 2009). The muscle recruitment affects the golf swing technique (Hume et al., 2005) and the ball trajectory as well (McHardy, Pollard & Luo, 2005).

The EMG patterns of the trunk muscles were the most focused studies during the golf swing (Bulbulian, Ball & Seaman, 2001; Cole & Grimshaw, 2008; Horton, Lindsay & Macintosh, 2001; Pink, Perry & Jobe, 1993; Watkins, Uppal, Perry, Pink & Dinsay, 1996; Silva et al., 2013), especially when related with the lower back injury (Cabri et al, 2009).

Some other EMG researches were performed in other body parts, as the scapula (Kao, Pink, Jobe & Perry, 1995) and the gleno-humeral joint (Jobe, Moynes & Antonelli, 1986; Jobe, Perry & Pink, 1989; Pink, Jobe & Perry, 1990).

To the best of our knowledge, there is only one published study that focuses the EMG pattern of the lower limb (Bechler, Jobe, Pink, Perry & Ruwe, 1995) describing the intensity of the neuromuscular solicitation during each phase in high skilled golfers. However, in this study the fine wire method was used and EMG signals were only recorded from proximal muscles acting on the hip and knee joints. The results found by Bechler et al. (1995) reported that the gluteus maximus was the most active muscle of the lower limb, especially on the right side during the takeaway and forward swing and on the left side during the acceleration and follow-through. Only one other study (Watkins et al., 1996) also retrieved similar neuromuscular patterns about the gluteus maximus but focused on the trunk muscles activation during the golf swing.

Lindsay, Horton & Vandervoort (2000) reported that at least 10% of the injuries occurred in the lower limb, especially in lower handicap golfers and the knee is the most affected structure. To Hume, Keogh & Reid (2005) golfing ability affects the peak of knee joint loads with larger forces in the high handicap rather than the low handicap golfers. The high handicap golfers may be exposed to injuries due to a poor or deficient technique (Bayes & Wadsworth, 2009) while in the low handicap golfers it may be due to overuse or a traumatic cause (Cabri et al., 2009).

Okuda, Graham and Bleakley (2010) reported significant differences between low and high handicap golfers in the pelvic horizontal rotation during the downswing and in the weight transfer to the lead lower limb. Wallance et al. (1990) also reported that the low handicap golfers showed significantly greater ground reaction force than the high handicap golfers on the trail leg during the backswing and on the lead foot during the downswing.

Therefore, the possibility that muscular demands of the lower limbs are affected by the differences of the handicap can be hypothesised and it is also supported by McHardy and Pollard (2005). In conclusion, the fact is there is a lack of EMG investigation on lower limbs muscles during the golf swing, the EMG of leg muscles were not yet reported and the only performed study was done with low handicap golfers (Marta, Silva, Castro, Pezarat-Correia & Cabri, 2012).

The objective of the present work is to compare the EMG patterns of lower limb muscles between the low and high handicap golfers. Furthermore, the neuromuscular patterns of the lower limb muscles will be described, in each phase, on the two studied groups and a new approach to the description of the knee and ankle muscles activity during the golf swing will be also reported.

Methods

Participants and task

Ten volunteer right-handed male golfers were recruited. Five high skilled with mean handicap of 0.7 ± 2.2 ranging from -1 to 4.5 and five low skilled with handicap of 25.5 ± 3.1 ranging from 22 to 29. The average age was 34.3 ± 7.4 years ranging from 20 to 45 with varied experience and different practice habits (Table 1). The participants were instructed to perform eight shots, taking into consideration their average distance, through an intermediate shot (between 100m and 150m) with a 7-iron golf club. The clubs had graphite shafts of standard length. Golfers performed the swing using their own club, glove and shoes on an artificial turf golf mat with high shock absorption characteristics, hitting a regular golf ball into a target placed at 6 m away.

The participants showed no limitation for golf practice (i.e. injuries) and accepted to complete the investigation protocol. All procedures and objectives of the study were explained to the participants who signed a written informed consent. The Research Ethics Committee of the Faculdade de Motricidade Humana, Universidade de Lisboa approved the study.

General procedures

After the explanation of study purposes and collection steps, the subjects answered a brief questionnaire about theirs characteristics. The skin was prepared and electrodes were placed. Then followed a warming up period of approximately five minutes. Later, EMGs of Maximal Voluntary Isometric Contraction (EMG_{MAX}) were collected for normalization of EMG signals. Reflective marks were placed for video analysis and synchronization procedures were performed. Before the experimental procedures and for a better adaptation to the task, all subjects were allowed to perform some swing trials and started the task when they assumed to be warmed up and ready.

Video data recording, processing and analysis

For kinematic analysis a three dimensions SIMI Motion 3D system (SIMI Reality Motion Systems GmbH, Unterschleissheim, Germany) was used with five high-speed cameras Basler A602fc (Basler Vision Technologies, Ahrensburg, Germany) at 100 Hz were used to identification of the golf swing phases. The cameras were placed at anterior, posterior and superior oblique, adjusted for the best 3D video analysis reconstruction. Two markers were placed on the individuals' clubs according to Horton et al. (2001).

Video data was synchronized with EMG data to divide the golf swing into five phases: (1) the Backswing – from the address to top of the swing; (2) the Forward Swing – from the top of the swing to the horizontal club (early part of Downswing); (3) the Acceleration – from the horizontal club to impact (late part of Downswing); (4) the Early

Follow-Through – from the impact to horizontal club; (5) the Late Follow-Through – from the horizontal club to the completion of the swing.

EMG data recording, processing and analysis

The electromyographic signals were collected after skin preparation by removing hair through skin abrasion and by cleaning it with alcohol in order to decrease the impedance of the interface between skin and electrode. Telemetric equipment bioPLUX® research 2010 (PLUX, Lisbon, Portugal) with Bluetooth connectivity with active surface electrodes (Al/AgCl, rectangular shape 30 x 22 mm) the AMBU® BlueSensor N (AMBU, Ballerup, Denmark) were used on the left and right sides of the following muscles: Semitendinosus (ST), Biceps Femoris (BF), Gluteus Maximus (GM), Vastus Medialis (VM), Vastus Lateralis (VL), Rectus Femuris (RF), Tibialis Anterior (TA), Peroneus Longus (PL), Gastrocnemius Medialis (GeM) and Gastrocnemius Lateralis (GeL). EMG signals were amplified with a bandpass (10-500 Hz), common-mode rejection ratio (CMRR) of 110 dB and input impedance greater than 100 M**Ω**. The EMG data were sampled at 1000 Hz, digitally filtered (10-490 Hz), full wave rectified, smoothed through a low-pass filter (12 Hz, fourth-order Butterworth digital filter). For amplitude normalization a reference of the peak 100-ms EMG signal (EMG_{MAX}) was used. The EMG average value was calculated during each phase of each repetition and subject. During processing a routine by MATLAB® software V.R2013a (The Mathworks Inc., Natick Massachusetts, USA) was used. To assure the EMG signals quality experienced researchers performed visual inspection of the EMG patterns before EMG processing.

The electrodes were aligned with muscle fibers orientation (center-to-center distance of 22 mm) at the most prominent part of the muscle bellies taking into account the following references (Hermens et al., 1999): ST - At 50% on the line between the ischial tuberosity and the medial epicondyle of the tíbia; BF - At 50% on the line between the ischial tuberosity and the lateral epicondyle of the tibia; GM - At 50% on the line between the sacral vertebrae and the greater trochanter just in the middle of the buttocks well above the visible bulge of the greater trochanter; VM - At 80% on the line between the anterior spina iliaca superior and the joint space in front of the anterior border of the medial ligament; VL - At 2/3 on the line from the anterior spina iliaca superior to the lateral side of the patella; RF - At 50% on the line from the anterior spina iliaca superior to the superior part of the patella; TA - At 1/3 on the line between the tip of the fibula and the tip of the medial malleoulus; PL - At 25% on the line between the tip of the head of the fibula to the tip of the lateral malleolus; GeM - In the most prominent bulge of the muscle; GeL - At 1/3 of the line between the head of the fibula and the heel. The ground electrode was placed over the manubrium sterni (Horton et al., 2001).

For each muscle two isometric repetitions of 3 to 4 seconds for determination of the EMG_{MAX} were performed. The EMG signal normalization was performed on grounds of the following protocols: BF and ST – In prone position press against the leg proximal to the ankle towards knee extension; GM – In prone position lift the complete leg (laterally rotated); RF, VM and VL – Extended knee without rotating the thigh while applying pressure against the leg above the ankle towards flexion; TA – Support the leg just above the ankle joint with the ankle joint in dorsiflexion and the foot inversion without extension of the great toe, and apply pressure against the medial side, dorsal surface of the foot in the direction of plantar flexion of the ankle joint and eversion of the foot; PL – Support the leg just above the ankle joint and everse the foot with plantar flexion of the ankle joint while applying pressure against the lateral border and sole of the foot, in the direction of inversion of the foot and dorsiflexion of the ankle joint; GeM and GeL – In single limb stance, plantar flexion of the foot with emphasis on pulling the heel upward more than pushing the forefoot downward; for maximal pressure in this position it is necessary to apply pressure against the forefoot as well as against the calcaneus.

To evaluate MVC the procedures described by Konrad (2005) and Hermens et al., (1999) were used. All participants were verbally encouraged during the maximal isometric efforts and, to avoid fatigue, 2 minutes rest was allowed between repetitions.

Statistical analysis

Data were processed in IBM SPSS Statistics 21.0 (IBM Corporation, New York, USA) software. Descriptive statistics were reported as mean±SD of % EMG_{MAX}. A mixed one-way repeated measures ANOVA was conducted to explore the differences between phases (%EMG_{MAX} and time) and handicap on each muscle from both sides. Besides the Central Limit Theorem data normality distribution was guaranteed by root square transformation. Statistical significances between measures were assessed by the Greenhouse-Geisser when the sphericity was violated. The Welch correction was performed when the homogeneity of variances was not verified between the handicap groups. Pairwise comparisons were performed with Bonferroni test. The significance level was set at $p<0.05$.

Results

Figure 1, Figure 2 and Figure 3 exhibit profile plots of the percentage values of EMG_{MAX} of each muscle in each phase between the two handicap groups.

Table 2 presents average time of different phases of the golf swing for the two handicap groups.

Comparison between phases

All muscles showed low or medium levels of activity (3 – 24% EMG_{MAX}) during the Backswing phase. In the Forward Swing the left and right gastrocnemius, right BF, right ST and right GM muscles reached its peak to medium to high levels of activity (23 – 94% EMG_{MAX}), while in the Acceleration phase the peak occurred in the left ST, left GM, right VM and right VL with medium to high levels of muscle activity (21 – 44% EMG_{MAX}). In the Early Follow-Through and Late Follow-Through all muscles decreased activity (5 – 60% EMG_{MAX}). The left VL, left VM, left TA, right PL and left PL reached their peak in the Forward Swing phase in the low handicap group while this event occurred in Late Follow-Through phase in the high handicap players. The right RF and left BF reached its peak in the Acceleration phase in the low handicap group and in the Early Follow-Through in the high handicap golfers. The right TA and left RF peaked during the Forward Swing in the low handicap golfers while in the high handicap group it occurred in the Acceleration phase. All the muscles showed significant differences between the peak phase and the other phases ($p<.005$).

Comparison between low and high handicap golfers

In the average swing time significant differences were found ($p<.050$) between the two handicap groups in the duration of all swing phases. The low handicap golfers exhibited significantly shorter swing phases than high handicap golfers in the Backswing, Forward Swing, Acceleration and Early Follow-Through while in the Late Follow-Through phase they exhibited longer ones. No statistical differences were found in the average Total Swing Time between groups ($p>.050$).

When EMG activity was compared between groups, significant differences were found especially on the left side. On the thigh the left BF, left ST, left GM, right VM and left RF muscles showed significant difference between groups ($p<.050$). On the leg the left TA, left PL, left GeL, right GeL and right GeM also showed significant differences ($p<.050$) between the low and high handicap golfers.

Discussion and implications

This study compares and describes the EMG patterns of lower limb muscles between the low and high handicap golfers during the different phases of the golf swing performed with an intermediate iron (7-iron). This is the first study that analyses the leg muscles activation in the golf swing and the first one that compares EMG patterns of lower limb muscles between low and high handicap golfers. Previous literature found differences between high and low handicap golfers in kinematic and weight transfer (Wallance et al., 1990; Barrentine, Fleisig & Johnson, 1994; Okuda et al., 2010). Subsequently, differences in activation patterns of the lower limb muscles can occur on golfers of different skill levels. Additionally, the neuromuscular patterns of the ankle, knee and hip muscles are also described.

In the present study, significant differences were not found in the overall duration of the swing, but the low handicap golfers showed a significantly lower duration in all phases except in the Late Follow-Through.

The Backswing starts with the loading of the body characterized by the right axial rotation (Gatt, Pavol, Parker & Grabiner, 1998) and the flexed knees at 20º-25º (Hume at al., 2005). This movement promotes the coil of the trunk, especially with activation of the abdominal oblique (Pink et al., 1993) preparing the next phase. In our study, as the body started to rotate, both lower limbs exhibited low to medium levels of activity (1-24% EMG_{MAX}) but the muscles of the right side, in general, showed a higher level of activity. Bechler et al. (1995) reported activation patterns similar to the ones retrieved by this study, but with higher values of EMG intensity. The EMG recording method and club differences can be the reason for the differences between values.

Comparing both groups, the reduced duration of the Backswing in the low handicap golfers is probably related to faster trunk movement allowing the development of a more efficient mechanism of Stretch-Shortening Cycle (Finni, Kegawa, Lepola & Komi, 2003) in order to potentiate the force production during the Forward Swing and Acceleration phases. The separation of the pelvis-upper torso (i.e. X-factor) and consequent trunk muscle stretch in the Backswing (Pink et al., 1993) implies the gain of the stretch reflex and elastic energy contributions through the eccentric activation of the muscles (Hellström, 2009, Myers et al., 2008) and the body weight transfer to increase the speed of the club through the proximal to distal kinetic chain (Hume et al., 2005). Concerning the differences in the muscular activation during this phase, the low and high handicap golfers showed significant differences in only a few muscles (ST, RF, TA, GeL from left side and right VM) but the subjects of both groups exhibited low magnitude values.

The Forward Swing is initiated by hip muscles contraction (Loock et al., 2013) and during this phase the club started increasing its speed as the pelvis rotated towards the target side (Burden, Grimshaw & Wallace, 1998). In the left tight, the anterior muscles (RF, VM, VL) presented their maximal activation (19-66% EMG_{MAX}) during this phase while as the posterior muscles showed medium activation levels (28-31% EMG_{MAX}). The right tight posterior muscles (BF, ST, GM) peaked to high levels of activity (47-94% EMG_{MAX}) while the knee extensors showed low levels of activity (5-13% EMG_{MAX}), resulting in the extension of the right hip.

The duration of the Forward Swing was shorter for the low handicap golfers with a difference of 66 ms in the average value. In this phase, the low handicap golfers showed higher levels of activity in all muscles of the left thigh (despite the fact that the significant difference in the quadriceps femoris occurred only in the RF). The portions of the left quadriceps femoris showed their peak (47-66% EMG_{MAX}) during this phase in low handicap golfers, probably to help position the knee over the target foot and support the forces applied to it. On the contrary, in the high handicap golfers those muscles peaked in the next phase. Those results are according to the findings that the low handicap golfers start the weight transfer from right to left earlier than the high handicap players (Okuda et al., 2010).

Previous researchers (Cabri et al., 2009; Lindsay et al., 2000; McHardy et al., 2006) reported that at least 11% of injuries in golfers occur in the lower limb, particularly in the left knee. The medial rotation, posterior and varus force at the end of the Acceleration and Follow-Through phases can worsen the knee condition, especially if complaints are frequent. To Gatt el al. (1998) the knee forces and moments are related with the swing characteristics and not with the golfers' skill. Therefore, some players can be prone to this injury if they swing with a lesser efficient technique (Batt, 1992), do a poor warming up or have insufficient physical condition (Cabri et al., 2009). In these phases, the stronger and earlier activation of the left quadriceps muscle in the low handicap golfers can help to stabilize the knee and support the forces that are applied to it (McHardy et al., 2006). An already sore knee can bring on an injury if off-balance muscle activation arises. This study showed that, during a swing, the low handicap players performed the Forward Swing with higher muscle activity in the anterior and posterior hip muscles from both sides, which can contribute to a more stable pelvis (Bechler et al., 1995) and a sooner weight transfer (Okuda et al., 2010).

Considering the EMG pattern of ankle muscles during the Forward Swing, with the exception of the left PL and right gastrocnemius (GeL and GeM) in the low handicap golfers, all muscles presented low to medium levels of activity (8-49% EMG_{MAX}). The left

PL reached its peak with high levels of activity (46-73% EMG_{MAX}) which can be related with the sooner weight transfer, especially in the low handicap golfers.

The kinetic transfer during the golf swing can be improved by the intermuscular coordination pattern. The low handicap golfers showed higher levels of activity on the TA and PL of the left ankle. The TA and PL muscle activation levels seem to be the first ground kinetic connection, especially in low handicap golfers, helping the core pelvic muscles (Loock et al., 2013) start the trunk acceleration. In the right lower limb the low handicap golfers presented much higher levels of activity on both portions of the gastrocnemius muscle than the high handicap golfers, suggesting that better golfers performed a powerful plantar flexion of the right ankle during this phase.

The Acceleration is the shortest phase (46-52 ms) and increases the club head speed (Okuda et al., 2010) from the sequential kinetic chain of the pelvis, trunk, arms and then the club (Hellström, 2009; Hume et al., 2005). The low handicap players (46 ± 7 ms) performed this phase shortlier than the high handicap golfers (52 ± 7 ms), as was stated by Zheng, Barrentine, Fleisig, and Andrews (2008). The left anterior thigh muscles continued their action with medium levels of activity while the right posterior thigh muscles dramatically decreased their activity (12-36% EMG_{MAX}). This muscle coordination can help to position the right lower limb through to the next phases and help a faster pelvis rotation. At the end of this event the knee supports a higher force load (Hume et al., 2005; Gatt et al., 1998) that might be associated to knee injuries described in literature (Lindsay et al., 2000; McHardy et al., 2006; Cabri et al., 2009), especially if some players frequently complain about knee pains. The posterior muscles of the left thigh (BF, ST, GM) continued to show higher levels of activity (29-49% EMG_{MAX}) which can be related with a sooner extension of the hip helping increase the rotation of the pelvis by creating a pivot (Vlad et al., 2004). In the left thigh the low handicap players exhibited higher activation levels in the posterior muscles and lower activation in the anterior muscles, especially in the RF that reached minimum levels of activity (8% EMG_{MAX}). This higher activation of the left quadriceps during Acceleration in the high handicap players can be related with the later weight transfer (Okuda et al., 2010) or a less efficient swing technique (Batt, 1992) of this group.

The left TA and left PL reached higher levels of activity (49-61% EMG_{MAX}) during Acceleration, especially in low handicap golfers that presented considerably stronger activations than the high handicap players, presumably to balance the body (Ferreira et al., 2012) during the weight transfer that occurs in this phase. This muscular behaviour also occurred in the left GM suggesting that these muscular groups should be more conditioned by the high handicap players, as stated by Loock et al. (2013).

The Early Follow-Through phase started after ball impact and the body decelerates. As it was verified in previous phases, the low handicap golfers performed this phase with shorter duration. Generally, the thigh muscles decreased their levels of activity (21-53% EMG_{MAX}), which could be related with the deceleration of the horizontal pelvis rotation to stabilize and to allow the action of the abdominal oblique to decrease the trunk rotation (Pink et al., 1993). The ankle muscles maintained the levels presented during the Acceleration phase (10-60% EMG_{MAX}). In the Early Follow-Through the low handicap golfers showed lower levels of activity in the left hamstrings and in the right vastus (VL, VM) and higher ones in the left GM, TA and PL.

In the Late Follow-Through, with the exception of the left PL (54-55% EMG_{MAX}) and the portions of the left quadriceps femoris of high handicap golfers (11-48% EMG_{MAX}), the studied muscles presented low levels of activation (3-17% EMG_{MAX}), especially in low handicap players. The Late Follow-Through was the only phase where the low handicap golfers presented longer duration, with a difference of 150 ms considering the average values of both groups, which is probably related with the higher angular velocities developed during the swing (Zheng et al., 2008). A tendency to exhibit higher levels of activity in the muscles of both thighs and in the right gastrocnemius (GeL, GeM) was observed in the high handicap players. As a matter of fact, this tendency was observed in the last two phases of the golf swing, suggesting that the low handicap golfers relax the thigh after impact, especially in the Late Follow-Through.

During the swing the low handicap golfers showed one peak in the muscle activation levels in all of the studied muscles, except in the right VL and right VM that exhibited two peaks. The first and higher peak occurred in the Acceleration phase and the second and lower peak was displayed in the Late Follow-Through phase. The high handicap golfers also exhibited two peaks in more muscles. This neuromuscular event can probably be related with a lesser efficient technique (Batt, 1992), so these patterns are less frequent in a more consistent swing technique.

The findings described in this study can help clinicians and coaches to build up intervention programmes, in order to minimize or prevent injuries, golf fitness training programmes and warming up routines of lower limb muscles to improve efficiency in the swing patterns. The muscles activation levels bring up the differences between the high and low handicap golfers supported by the early weight transfer and pelvis rotation (Okuda et al., 2010) in the last mentioned group.

Conclusion

The activation levels of the lower limbs were characterized and compared during the swing phases in the low and high handicap golfers. The studied muscles reached their peak during the Forward Swing and Acceleration phases.

The low handicap golfers performed the swing with shorter duration of all swing phases except for the Late Follow-Through, which was longer.

The main differences in muscular patterns between golfers of different levels were found in the left lower limb with a tendency for a higher activation level on the low handicap golfers. The main differences observed in the present study were that low handicap golfers: i) presented the maximum activation of the left quadriceps femoris during the Forward Swing whereas the high handicap displayed it during the Acceleration phase, ii) showed a much stronger activation of the right gastrocnemius muscle during the Forward Swing, iii) exhibited lower levels of activity in the muscles of both thighs and in the right gastrocnemius during the Early and Late Follow-Through phases, suggesting that these golfers relax these muscles after impact.

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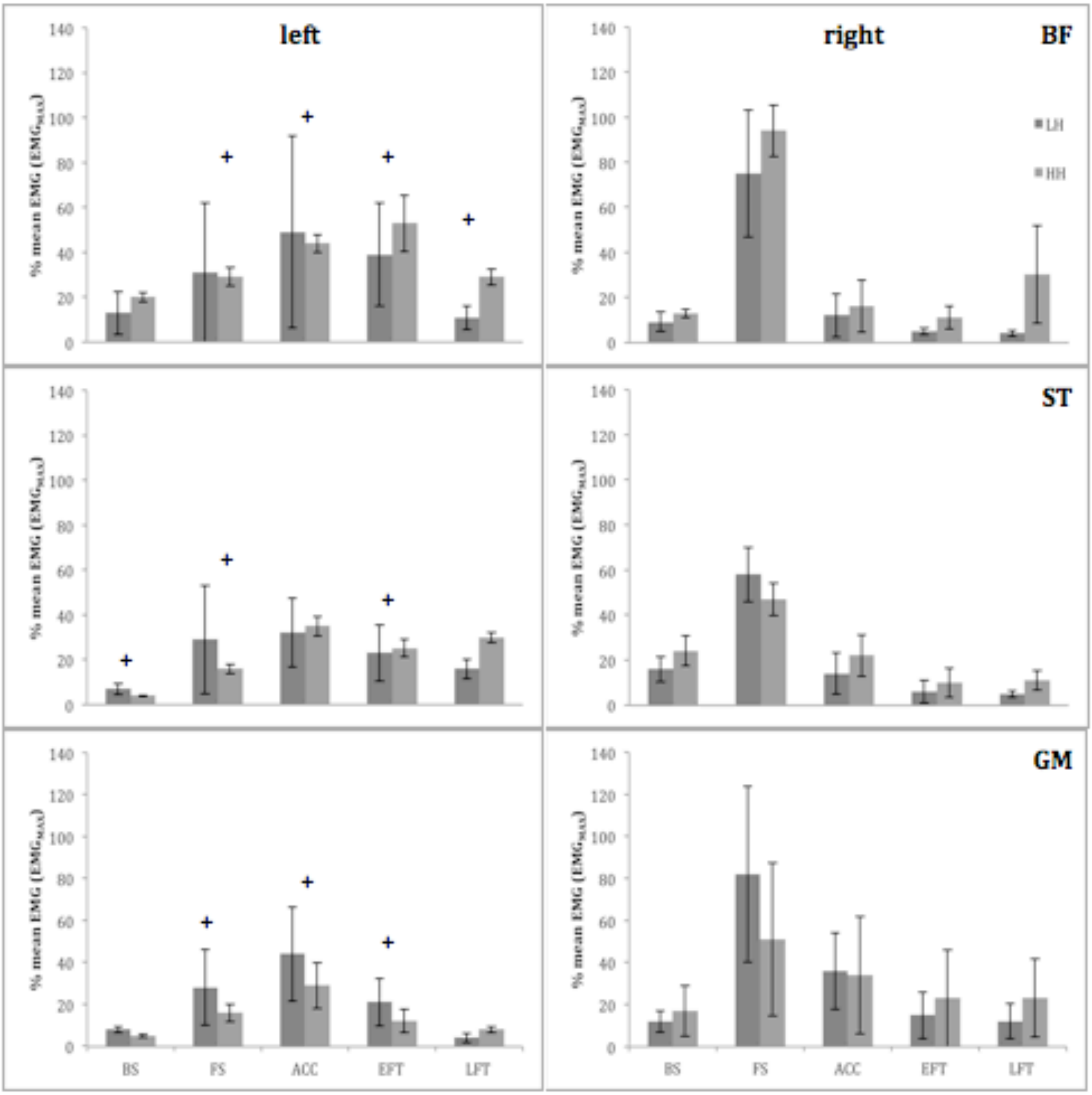

Figure 1 – Average percentage value of normalized EMG (EMG_{MAX}) from the posterior hip by muscle laterality on each phase for each handicap group.

Legend: BF – biceps femoris; ST – semitendinosus; GM – gluteus maximus; BS – Backswing; FS – Forward Swing; ACC – Acceleration; EFT – Early Follow-Through; LFT – Late Follow-Through; LH – low handicap group; HH – high handicap group. + – significant differences between the low and high handicap golfers.

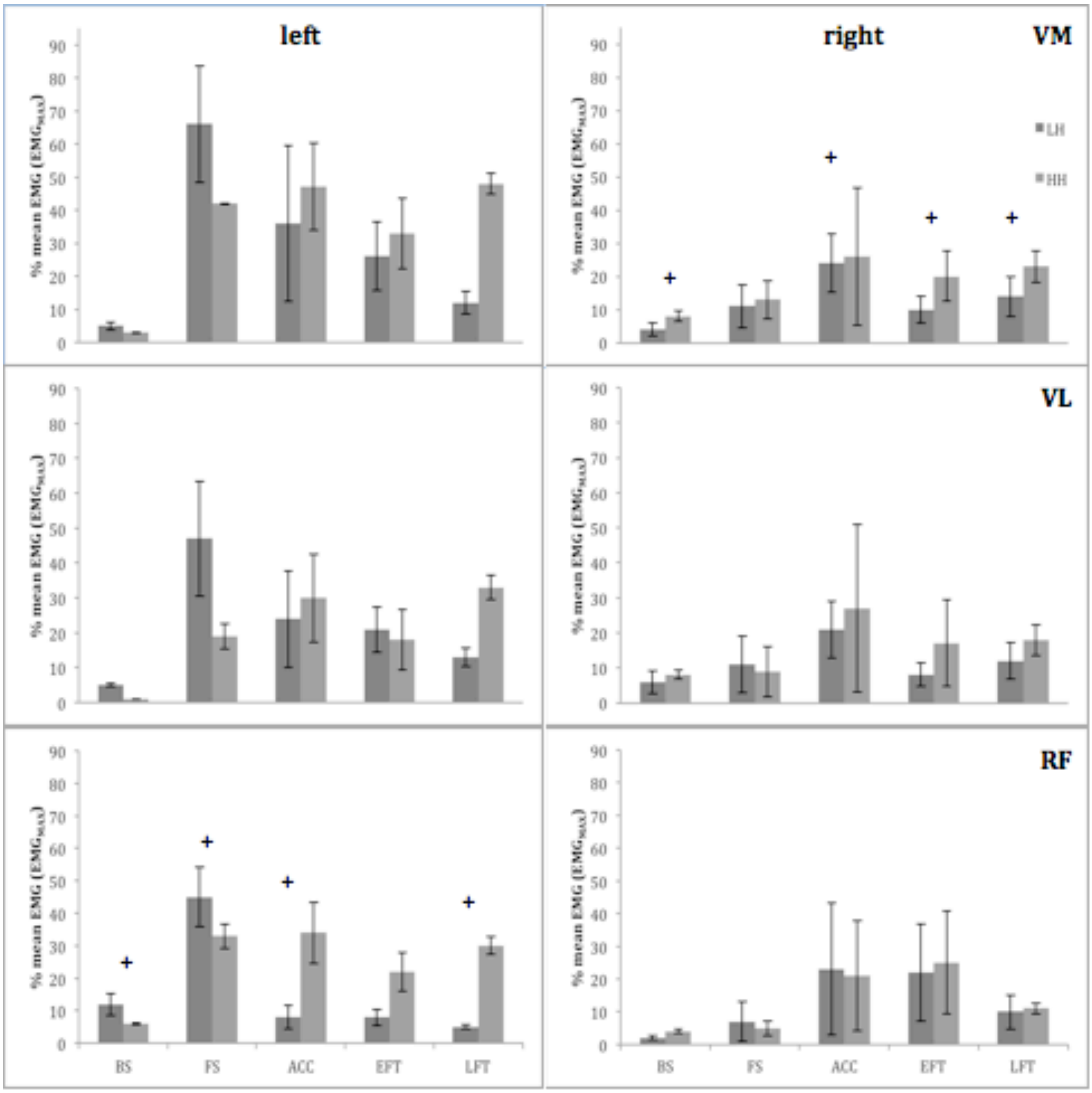

Figure 2 - Average percentage value of normalized EMG (EMG$_{MAX}$) from the anterior hip by muscle laterality on each phase for each handicap group.
Legend: VM – vastus medialis; VL – vastus lateralis; RF – rectus femoris; BS – Backswing; FS – Forward Swing; ACC – Acceleration; EFT – Early Follow-Through; LFT – Late Follow-Through; LH – low handicap group; HH – high handicap group. + – significant differences between the low and high handicap golfers.

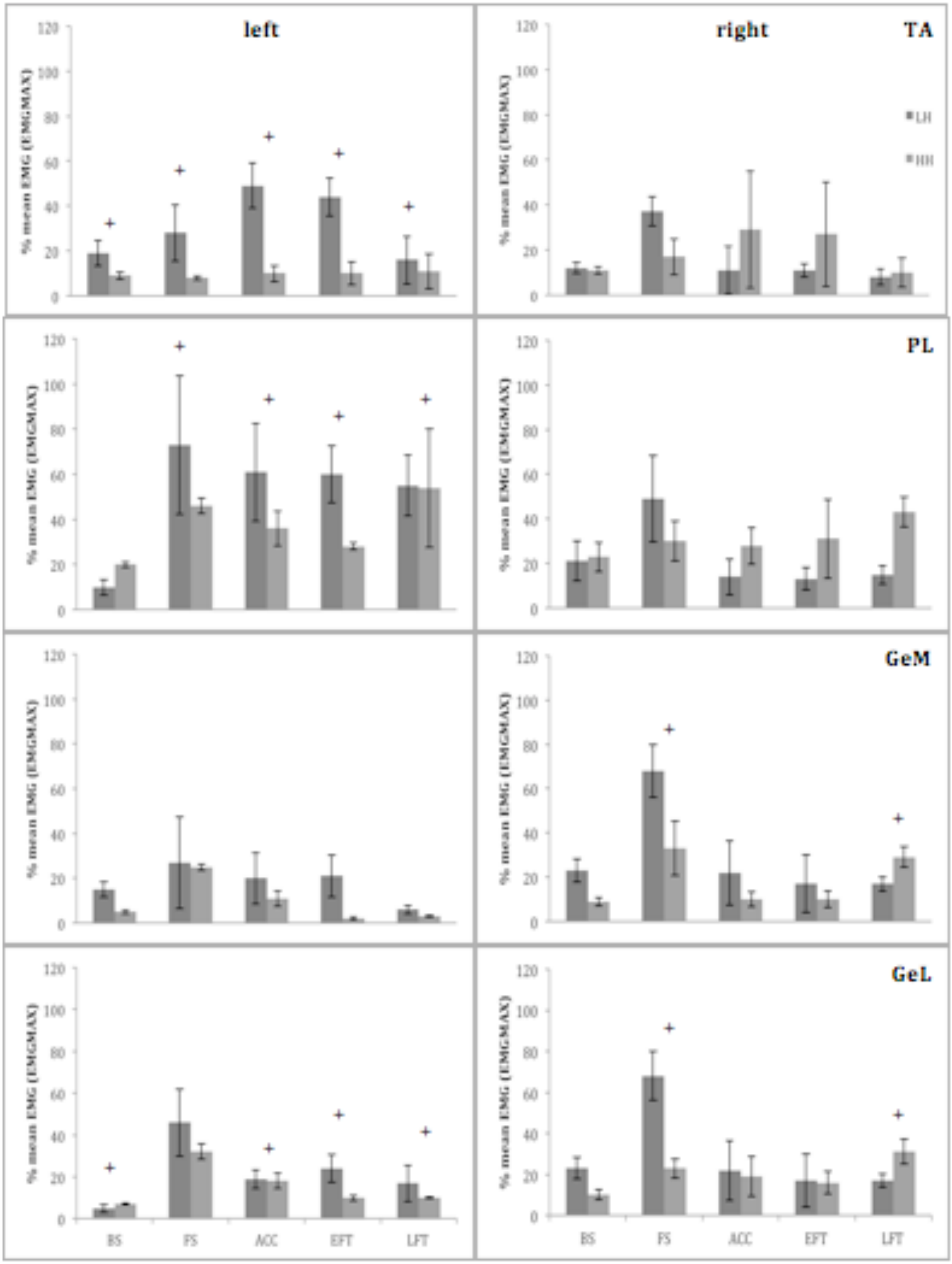

Figure 3 - Average percentage value of normalized EMG (EMG_{MAX}) from the leg by muscle laterality on each phase for each handicap group.
Legend: TA – tibialis anterior; PL – peroneus longus; GeM – gastrocnemius medialis; GeL – gastrocnemius lateralis; BS – Backswing; FS – Forward Swing; ACC – Acceleration; EFT – Early Follow-Through; LFT – Late Follow-Through; LH – low handicap group; HH – high handicap group. + – significant differences between the low and high handicap golfers;

Table 1 - Participants characteristics

Group (*n* = 10)	Characteristics	mean ± SD	range
Low handicap (*n* = 5)	Handicap	0.7 ± 2.2	(-1 – 4.5)
	Height (m)	1.72 ± 0.1	(1.68 – 1.82)
	Body Mass (kg)	70.6 ± 4.9	(67.0 – 79.0)
	Age (yr)	30.0 ± 6.8	(20.0 – 36.0)
	Experience (yr)	19.2 ± 4.4	(12.0 – 22.0)
High handicap (*n* = 5)	Handicap	25.5 ± 3.1	(22.0 – 29.0)
	Height (m)	1.76 ± 0.1	(1.70 – 1.83)
	Body Mass (kg)	85.8 ± 13.9	(70.0 – 108.0)
	Age (yr)	42.0 ± 4.5	(34.0 – 45.0)
	Experience (yr)	6.8 ± 7.5	(2.0 – 20.0)

Table 2: Swing phases average time (mean ± SD) from the 7-iron club expressed in milliseconds (ms).

group	**Backswing** **+ (p=.001)**	**Forward Swing** **+ (p<.001)**	**Acceleration** **+ (p=.001)**	**Early Follow-Through** **+ (p<.001)**	**Late Follow-Through** **+ (p<.001)**	Total Swing Time (p=.433)
low handicap	**828 ± 127**	**197 ± 22**	**46 ± 7**	**65 ± 5**	**661 ± 181**	1805 ± 226
high handicap	**949 ± 149**	**263 ± 31**	**52 ± 7**	**92 ± 12**	**510 ± 153**	1865 ± 245

\+ – significant diferences between group calculated by ANOVA test (p<.050).

Capítulo 8 – Discussão Geral

O principal objetivo da presente tese foi caracterizar, com recurso a EMG de superfície, a intensidade de solicitação neuromuscular durante as diferentes fases do *swing* em golfistas de diferentes níveis (*handicaps*). Adicionalmente, procurámos analisar a influência da utilização de diferentes tacos nos padrões neuromusculares.

Numa primeira etapa procedeu-se à revisão e análise crítica de literatura existente sobre a atividade eletromiográfica no *swing* de golfe (estudo I). Posteriormente, desenvolvemos um estudo caso (estudo II), apenas com três sujeitos (*handicap* <5), visando a caraterização do padrão EMG no membro superior dominante durante o *swing*. Esse estudo teve também como objetivo a definição e testagem da metodologia a usar nos estudos posteriores, nomeadamente o desenvolvimento de rotinas automáticas de processamento do sinal EMG em Matlab para agilização do tratamento de dados. Na terceira e última etapa, foram realizados estudos sobre os padrões eletromiográficos durante o *swing* de golfe relativos aos músculos do tronco (estudo III) e membros inferiores (estudos IV e V).

A revisão de literatura (estudo I) focou a sua atenção em artigos científicos com os termos "golfe", "EMG", e "*swing*". Foram encontrados no total dezanove artigos. Treze são artigos originais (seis sobre o tronco,[1-6] quatro sobre o ombro,[7-10] dois sobre o antebraço,[11,12] um sobre o membro inferior[13]) e seis são artigos de revisão de literatura (um geral sobre a atividade neuromuscular no golfe,[14] dois sobre o desporto em geral no membro superior[15] e ombro[16], e três sobre lesões no golfe).[17-19] Grande número dos artigos encontrados foi elaborado pelo mesmo grupo de investigadores,[1,2,7-10,13] mas focando essencialmente o tronco e a cintura escapular. O estudo I foi determinante em algumas das opções posteriormente assumidas, por duas ordens de razões: a) ao evidenciar, no âmbito da investigação sobre a caraterização da participação muscular durante o *swing*, os aspetos relevantes não estudados e que justificaram os objetivos dos estudos que elaborámos posteriormente e, b) ao permitir uma revisão crítica da metodologia utilizada na literatura que evidenciasse as limitações desses estudos e clarificasse o significado dos seus resultados.

Os resultados desta revisão de literatura evidenciaram as dificuldades de comparação dos artigos produzidos devido, por um lado, à heterogeneidade dos jogadores estudados e, por outro, às diferenças metodológicas utilizadas na recolha, processamento e análise do sinal EMG nos diferentes estudos, e que dificultam em muitos casos a comparação dos resultados obtidos.

A utilização de técnicas de EMG recorrendo em alguns estudos a elétrodos de profundidade e noutros a elétrodos de superfície é um fator limitativo quando se pretende uma análise comparativa entre resultados. A EMG de profundidade, ao recolher potenciais elétricos gerados em algumas fibras musculares mais próximas do elétrodo de detecção, não é representativa da atividade total do músculo.[14] No entanto, também o tipo de elétrodo usado e a sua colocação precisa é pouco descrito nos diferentes estudos analisados que recorreram a EMG de superfície. O método de normalização do sinal de EMG é também um aspeto de diferenciação, dado poderem ser encontrados estudos com diferentes referências de normalização, como o teste submáximo ou a contração voluntária máxima, e até estudos que não normalizam os sinais. A normalização do EMG obtida pela atividade desenvolvida durante a contração voluntária máxima, para além permitir a comparação entre diferentes condições, fornece uma medida indicativa do nível relativo de solicitação muscular durante a tareda em estudo. A uniformização de procedimentos de colocação dos elétrodos e de determinação da contração voluntária máxima descritos na literatura por autores como McGill,[15] e Hermens el al.,[16] podem ser uma boa aproximação no sentido de comparar os resultados de estudos de diferentes laboratórios.

A pouca informação encontrada sobre os parâmetros temporais no *swing* do golfe, com apenas dois estudos publicados,[17,18] foi outra lacuna evidenciada na revisão de literatura elaborada no estudo I. Além disso, esses estudos utilizaram diferentes métodos de determinação dos parâmetros de tempo, nomeadamente do limiar e da janela de tempo considerada, o que dificulta a comparação de resultados. A problemática da definição da metodologia mais adequada à definição do parâmetro temporal mais estudado, o início de ativação (*onset*), carece de mais investigação. Apesar desta tese se centrar apenas na caracterização dos parâmetros de intensidade EMG também contribuímos como coautor para um artigo[19] publicado sobre a avaliação de diferentes formas de determinação do *onset* em músculos do tronco durante o *swing* de golfe.

Em suma, a análise crítica realizada no estudo I foi importante na definição das opções metodológicas envolvidas na recolha e tratamentos dos sinais EMG nos estudos posteriores da presente tese.

A revisão de literatura que fizemos evidenciou também a existência de uma única publicação centrada na comparação dos padrões neuromusculares (da musculatura do antebraço) em jogadores de diferentes *handicap*.[12] A maioria das pesquisas em EMG foi conduzida em jogadores de golfe de alto nível, profissionais ou com baixo *handicap* (<5), já que eles representam a maior proficiência dos padrões neuromusculares. Contudo, os resultados obtidos com estes jogadores não refletem os padrões neuromusculares da maior parte dos jogadores de golfe, que corresponde ao jogador médio, com menor reprodutibilidade e eficiência do swing do golfe.

Na literatura consultada poucas observações incluem EMG em diferentes regiões do corpo simultaneamente. A maior parte dos estudos focam a sua atenção na musculatura do membro superior,[7-12] na parede abdominal e nos músculos extensores do tronco,[1-6] negligenciando o membro inferior, onde apenas um estudo foi realizado[13] e com elétrodos de profundidade. Essa lacuna na investigação produzida foi determinante na opção pelos estudos IV e V.

No estudo II foi estudado o padrão neuromuscular no membro superior dominante em três jogadores de golfe com baixo *handicap* (≤ 5) que executaram três tipos de *swing* (velocidade e amplitude normais, velocidade lenta e amplitude normal e, velocidade normal e amplitude mais reduzida no *Backswing*). Os resultados mostraram que, no membro superior dominante, os níveis mais elevados de ativação ocorreram durante o *Downswing,* e que os músculos adutores do braço (28–56 $\%EMG_{MAX}$) extensores do cotovelo (30–59 $\%EMG_{MAX}$) e os flexores do punho (31–76 $\%EMG_{MAX}$) foram os músculos mais intensamente solicitados. Refira-se que, tanto quanto é do nosso conhecimento, o músculo tricípite braquial, tal como o bicípite braquial, não haviam sido previamente objeto de análise em nenhum estudo.

Paralelamente, este estudo piloto serviu também para definir e testar os aspetos metodológicos utilizados na análise cinemática e na recolha e processamento do sinal EMG nos estudos posteriores. Foram desenvolvidas e testadas as rotinas Matlab que permitiram a automatização dos diferentes passos envolvidos na transformação do sinal EMG em bruto e na determinação dos parâmetros a analisar. A análise dos resultados obtidos e do processo que a isso conduziu aponta no sentido de, paralelamente à utilização de mecanismos automáticos de tratamento, ser indispensável a existência de fases de inspeção visual dos sinais. Numa fase inicial, a confirmação dos dados em bruto deverá ser assegurada através de inspeção visual para aferir da qualidade dos sinais e despistar eventuais artefactos. Após a aplicação das rotinas é sempre necessária uma nova inspeção visual de saída para verificar o ajustamento dos resultados obtidos pelas rotinas aos fenómenos que realmente são objeto de análise. Verificámos neste estudo que esta coexistência entre o processamento automático e a inspeção visual é particularmente importante no caso de quantificação dos parâmetros temporais do EMG, o que foi mais tarde confirmado no estudo que realizámos em colaboração sobre a determinação do *onset* de músculos do tronco durante o *swing*.[19]

O estudo III foi realizado versando como objetivo principal a caraterização dos músculos do tronco durante o swing numa amostra de oito jogadores com *handicap* de nível médio (15.7± 3.2). Como resultados mais relevantes, os jogadores médios mostraram a existência de um pico de atividade muscular durante a fase de *Forward Swing* que contribui para o aumento da velocidade de rotação do tronco, principalmente através do músculo oblíquo externo direito, tal como foi descrito por Pink et al.[1] O grande glúteo direito também exibiu um máximo de atividade durante a mesma fase, que está provavelmente associado à extensão da coxa e a transferência de peso do membro inferior direito para o esquerdo (em jogadores dextros) tal como encontrado, mas com valores mais elevados, por Bechler et al.,[13] Já na fase de *Acceleration* o grande glúteo esquerdo atingiu o seu máximo o que relacionamos com a transferência de peso para o lado esquerdo assistindo à rotação da pélvis e à extensão da coxa.[13] Estudos previos[1,2] verificaram níveis de ativação elevados nos músculos erectores da coluna, principalmente durante a fase de *Forward Swing* e *Acceleration* para o lado direito e esquerdo, respetivamente. Os jogadores médios apresentam menores níveis de ativação dos músculos eretores da coluna quando comparados com os jogadores com melhor nível de desempenho. A coordenação intermuscular dos músculos grande oblíquo esquerdo e os eretores da coluna pode estar associada a dores na região lombar, a lesão mais frequente no golfista[20], já que os jogadores com *handicap* mais elevado apresentam uma menor eficiência técnica.

Na revisão bibliográfica efetuada, apenas um estudo[13] dedicou a sua atenção à análise eletromiográfica do membro inferior. Esse estudo foi realizado exclusivamente com golfistas com baixo *handicap* (<5), e o registo EMG foi efetuado através de elétrodos de profundidade, uma técnica de recolha que, além de fornecer um registo EMG que não pode ser considerado representativo da globalidade do músculo, tem um caráter mais intrusivo que a recolha através de elétrodos de superfície. Estas limitações, associadas à inexistência de dados EMG sobre a musculatura mais distal do membro inferior, justificaram os nossos estudos IV e V que se centraram na análise da participação muscular da musculatura do membro inferior no *swing*.

No estudo IV pretendeu-se caraterizar o padrão eletromiográfico dos músculos do membro inferior em jogadores com *handicap* médio (n = 14). Tal como verificámos na musculatura do tronco, os músculos do membro inferior mostraram ativação mais intensa durante as fases de *Forward Swing* e *Acceleration*. Mais especificamente, os músculos posteriores da coxa direita e os músculos anteriores da coxa esquerda alcançaram o máximo de ativação durante a fase de *Forward Swing* enquanto que os músculos anteriores da coxa direita e os músculos posteriores da coxa esquerda obtiveram esse mesmo máximo de ativação na fase de *Acceleration*, contribuindo para a rotação da pélvis através de um fulcro de rotação no membro inferior esquerdo,[21] tal como é indiciado por Bechler et al.[13] Estes músculos têm um papel vital no início do movimento de swing e na sua continuação[22] através da transferência de energia da cadeia cinética iniciada no membro inferior com passagem pelo tronco, membros superior, taco e, finalmente, a bola. Na perna, os músculos tibial anterior direito, longo peroneal direito e as duas porções dos gémeos dos dois lados desenvolveram o seu pico de ativação durante a fase de *Forward Swing*, enquanto que os músculos tibial anterior esquerdo e longo peroneal esquerdo exibiram o seu máximo durante a fase de *Acceleration*. Estes níveis de ativação podem estar relacionados com a posição inicial do *swing* (face ao tamanho do taco utilizado), à reação ao desequilíbrio[23] devido à relação de rotação entre a cintura pélvica e a cintura escapular (*X-fator*), ou à transferência do peso do lado direito para o lado direito.[24] O padrões musculares descritos no membro inferior podem estar interligados com a transferência de peso existente durante as fases de *Forward Swing* e *Acceleration* entre os membros inferiores direito e esquerdo (num jogador dextro).

Também no âmbito da análise da atividade neuromuscular no membro inferior durante o *swing* do golfe, o estudo V propôs-se avaliar a influência do *handicap* no padrão EMG da musculatura do membro inferior no swing executado com o ferro-7. Optámos por este taco por ser um dos mais utilizados no golfe, estando adaptado a um *swing* de distância intermédia. Foi feita a comparação entre dois grupos distintos em função do handicap: baixo *handicap* (<5) e alto *handicap* (>22). Em cada grupo integrámos cinco participantes. Poderíamos ter aumentado o número de sujeitos em cada grupo aceitando maior variabilidade no handicap, mas optámos por grupos mais reduzidos aumentando desta forma a consistência no *handicap* dos golfistas. Investigações anteriores[24-26] mostraram diferenças significativas na cinemática e na cinética associadas à transferência de peso quando foram comparados golfistas de diferentes handicaps.

No presente estudo o grupo com baixo *handicap* apresentou menor duração de todas as fases, à exceção da *Late Follow-Through* que foi mais longa. Esta reduzida duração pode estar relacionada com um eventual melhor aproveitamento do ciclo muscular alongamento-encurtamento[27] ao nível do tronco, com consequência nas fases seguintes devido ao aumento de velocidade da rotação do tronco.[28] O músculo quadricípite crural esquerdo atingiu o seu máximo de atividade durante a fase de *Forward Swing* nos jogadores de baixo *handicap*, enquanto que nos golfistas de alto *handicap* tal aconteceu na fase de *Acceleration*. Este atraso na ocorrência do máximo de ativação deste importante músculo do membro inferior entre os grupos pode ser explicado pelo facto de a transferência de peso para o membro inferior esquerdo (em jogadores dextros) acontecer mais cedo em jogadores com baixo *handicap*.[24] Os gémeos da perna direita também apresentaram forte ativação muscular durante a fase de *Forward Swing*, sugerindo que os jogadores com baixo *handicap* realizam uma potente flexão plantar apresentando diferenças significativas em relação ao jogadores com elevado *handicap*. As ativações dos músculos tibial anterior e longo peroneal lateral da perna esquerda durante a fase de *Aceleration* podem estar associadas à manutenção do equilíbrio do corpo, principalmente nos jogadores com baixo *handicap* na fase de *Backswing* (X-fator) e na *Acceleration* (transferência de peso), mas sem diferenças significativas entre os grupos. No entanto, foram encontradas diferenças significativas entre os grupos na perna direita para os músculos tibial anterior na fase de *Acceleration* e do longo peroneal na fase de *Forward Swing*, podendo essa diferença estar relacionada com a transferência de peso que ocorre mais cedo no grupo com baixo *handicap*[24] ou uma à ineficiência do gesto técnico de swing demonstrada pelos jogadores de nível médio.[29] Foi ainda observado que os músculos da coxa e os gémeos direitos exibiram nos jogadores com baixo *handicap* valores mais baixos de ativação durante as duas fases em que dividimos a *Follow-Through*, sugerindo que os jogadores de nível mais elevado promovem um relaxamento mais acentuado destes grupos musculares após o impacto.

Segundo Egret et al.,[30] o tipo de taco tem influência na velocidade da cabeça do mesmo e na cinemática do tronco durante o *swing*. Também Okuda et al.[24] encontrou diferenças significativas na rotação horizontal do tronco em jogadores com baixo *handicap* a meio do *Backswing*. No entanto, apesar de estarem descritas diferenças cinemáticas e na velocidade da cabeça do taco quando o *swing* é executado com diferentes tipos de taco, pela revisão de literatura concluímos que a influência do tipo de taco nos padrões neuromusculares produzidos durante o *swing* não havia ainda sido estudada. O conhecimento desse efeito é importante já que a utilização de tacos com diferentes dimensões e adaptados a *swings* com diferentes objetivos, pode ter influência no risco de lesões músculo-esqueléticas, principalmente de lesões lombares. Por isso incluímos esse objetivo nos estudos III e IV.

No estudo III foram comparados os padrões de ativação da musculatura do tronco no swing efetuado com dois tipos de taco (*pitching wedge* e ferro-4, sendo os tacos dos extremos alcançando distâncias inferiores a 100m e superiores a 150m, respetivamente). Verificámos que o uso dos dois tipos de taco não produziu alterações no padrão neuromuscular dos músculos do tronco. No entanto, esses resultados podem também ter sido influenciados pelo número relativamente reduzido de jogadores estudados (oito) associado à elevada variabilidade individual verificada nos parâmetros em estudo.

No estudo IV comparámos o padrão eletromiográfico dos músculos do membro inferior no swing executado com três diferentes tipos de taco (*pitching wedge*, ferro-7, ferro-4). Os ferros têm tamanhos e ângulos da cabeça do taco diferentes, sendo utilizados para se alcançarem diferentes distâncias no *swing*. Quanto menor o número do ferro, menor é o ângulo e maior o tamanho, servindo para alcançar maiores distâncias, mas com menor precisão, sendo o *pitching wedge* o mais pequeno dos tacos estudados e consequentemente o mais preciso. Foram encontradas diferenças de intensidade de ativação muscular significativas entre os diferentes tipos de taco. Na maioria dos casos verificámos valores de ativação mais elevados quando o swing foi realizado com a utilização do ferro-4. Especificamente, foram detetadas diferenças no semitendinoso esquerdo, no vasto interno e reto femoral do quadricípite crural direito, entre os tacos *pitching wedge* e ferro-4. Alguns investigadores[20,31,32] referem que o joelho, mais propriamente o do lado esquerdo, é uma das regiões do membro inferior que está mais sujeita a lesão, também devido à sobrecarga,[32] principalmente nas fases de *Acceleration* e de *Follow-Through*. O maior nível de ativação do quadricípite crural quando o *swing* foi realizado com o taco maior (ferro-4) pode contribuir para suportar o aumento de carga devido à maior distância que a que a bola é lançada. Investigação prévia[33] verificou que os momentos e os picos de força não estão relacionados com o *handicap* do jogador mas com as características do swing. Consequentemente, se existir algum desconforto ou queixa nessa região, tal pode aumentar o risco de incidência de lesão por fratura, devido ao aumento de carga, tal como foi referido por alguns investigadores.[34,35]

Em síntese, os aspetos referentes à participação neuromuscular durante o *swing* evidenciados dos estudos que foram apresentados na presente tese, bem como a influência do tipo de taco utilizado ou o *handicap* do jogador, podem constituir informação relevante para os investigadores, treinadores, e clínicos na procura incessante de compreensão de formas de potenciar a performance através do processo de treino e de condicionamento físico, bem como no processo de prevenção de lesões de natureza músculo-esquelética.

Limitações do Estudo e Perspetivas de Investigação Futura

Nos estudos laboratoriais que realizámos as amostras foram selecionadas por conveniência pela formação de grupos por *handicap*. O número de participantes em alguns dos estudo foi reduzido. Uma das dificuldades enfrentadas relacionou-se com a morosidade nas recolhas de dados (com uma duração média de 1 hora e 45 minutos) o que, aliado à pouca disponibilidade dos golfistas, poderá ter condicionado a sua colaboração. Para além de todo o processo de preparação da pele e colocação de superfícies de detecção e de marcas refletoras para a análise cinemática (com uma duração média de 40 minutos), a execução determinação de contrações voluntárias máximas para obter o valor EMG de referência na normalização é um processo moroso (com uma duração média de 20 minutos), mas fundamental para comparar condições e resultados de estudos de diferentes laboratórios. É também importante para fornecer uma medida relativa de solicitação muscular que sirva de orientação do processo de treino.

A utilização de EMG de superfície é outra limitação apresentada já que não é possível aceder a músculos das camadas mais profundas que podem ter um papel importante na relação mobilidade/estabilidade dos diferentes segmentos corporais durante o *swing*. Os músculos transverso abdominal e psoas ilíaco no estudo do tronco, e os músculos pélvi-trocantéricos no membro inferior, são exemplos disso.

O tempo de prática de cada jogador não foi controlado, o que pode interferir nos padrões neuromusculares dos jogadores, apesar do seu *handicap*. Alguns golfistas podem passar mais tempo no *driving range* e menos em competição/torneio, tendo alterações no seu resultado de *handicap*. Esta variável deverá ser considerada em novos estudos.

Os estudos que compõem esta tese foram realizados com golfistas do género masculino. Era nossa intenção avaliar também golfistas do género feminino e na realidade procedemos à avaliação de algumas golfistas. No entanto, em consequência de um universo de jogadoras nacionais limitado, não nos foi possível obter um número suficiente de sujeitos para constituir um grupo só do género feminino. Optámos por não misturar golfistas dos dois géneros, atendendo às diferenças de composição corporal e de capacidade muscular entre ambos. No entanto, em termos futuros, os novos estudos deverão procurar estudar a participação muscular no swing no género feminino, para perceber se, em função das diferenças de capacidade muscular e de morfologia, estamos perante padrões de coordenação neuromuscular diferentes dos evidenciados pelo género masculino.

Apesar destas limitações, consideramos que as conclusões dos estudos que incluem esta tese evidenciam tendências importantes sobre o comportamento muscular no swing que poderão ser aproveitados para os profissionais que se preocupam com o rendimento e com a prevenção das lesões mais frequentes do *swing* no golfe.

Perspetivando o futuro desta linha de investigação, a integração de parâmetros eletromiográficos de intensidade, parâmetros temporais e variáveis cinemáticas e cinéticas permitirá melhor compreender como o sistema motor se organiza na melhoria da produção do *swing* ao longo do processo de prática e aprendizagem. A realização de estudos longitudinais possibilitará a compreensão da aquisição e consolidação dos processos de coordenação intermuscular do gesto técnico associados à melhoria do *handicap* ao longo do tempo, numa tarefa complexa, como é o *swing* do golfe.

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Capítulo 9 – Conclusões

Os diferentes estudos realizados e os resultados obtidos permitem extrair um conjunto de conclusões relativamente à participação neuromuscular no swing de golfe. Para além do contributo científico para o melhor conhecimento dos processos de coordenação neuromuscular no gesto, estes resultados constituem informação útil para uma melhor compreensão e orientação na prevenção de lesões bem como nos processos de treino e de condicionamento físico do golfista:

a) as fases de maior atividade muscular na musculatura do membro superior dominante, tronco e membro inferior são o *Forward Swing* e a *Acceleration*;
b) no jogador de baixo handicap, e considerando os músculos monitorizados do membro superior dominante, o deltoide posterior, grande dorsal, vasto lateral do tricípite braquial e os flexores do punho, foram os que apresentaram o maior intensidade de solicitação;
c) no jogador de nível médio, e considerando os músculos monitorizados do tronco, o oblíquo externo direito, foi o que apresentou o maior intensidade de solicitação.
d) no jogador de nível médio, e considerando os músculos monitorizados do membro inferior, o semitendinoso direito, vasto interno do quadricípite crural esquerdo, bicípite femoral e grande glúteo dos dois lados, foram os que apresentaram o maior intensidade de solicitação.
e) não se verificaram diferenças de intensidade de ativação dos músculos do tronco quando o swing foi executado pelo jogador médio com os tacos *pitching wedge* e ferro-4;
f) no jogador de nível médio a execução do *swing* com diferentes tacos (*pitching wedge*, ferro-7, ferro-4) implicou diferenças na intensidade de solicitação muscular no membro inferior, principalmente do lado direito;
g) no *swing* com o *pitching wedge* verificou-se uma tendência de valores de ativação muscular mais baixos no membro inferior do que quando o *swing* foi realizado com os outros tacos (ferro-7 e ferro-4).
h) no swing executado com o ferro-7, existem diferenças significativas entre os jogadores com alto e baixo *handicap* na musculatura do membro inferior, principalmente do lado esquerdo;

i) o movimento de swing do golfe necessita de mais investigação para ser possível compreender a organização do sistema motor num gesto complexo.

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ANEXOS

ANEXO 1

(Rotinas – Estudo II)

Rotina de Intensidade:

```
% ***********************************************
% *                LOAD FILE NAME             *
% ***********************************************
clear all;
clc;
SR=1000;
dt=1/SR;
%**********************************************
%*    Abrir os ficheiros das coordenadas     *
%**********************************************
ext='.txt';
fileMax={['MaximosSAL' ext]};
Maxfile=char(fileMax);
MaximosLUIS=load(Maxfile);
nome={['r02' ext];};
%--------//-----------//--------//------
comp=length(nome);
%--------//-----------//--------//------
for j=1:comp
file=char(nome(j));
DadosRaw=load(file);
Lgh(j)=length(DadosRaw);
%   figure
%   h=plot(Dados)
end
viragem(1,1)=989;
viragem(1,2)=1946;
viragem(1,3)=2177;
viragem(1,4)=2677;
DadosRaw=DadosRaw(viragem(1,1):viragem(1,4),:);
viragem=viragem-viragem(1)+1;
for j=1:comp
Lgh(j)=length(DadosRaw);
end
minLgh=min(Lgh);
%*******************
%*    Suavização *
%*******************
cut1=500 ;cut2=15;
 [HDMal]=HPassF(DadosRaw(:,1:14),cut1,cut2,SR,minLgh);
%******************
%*    Retifica    *
%******************
 [rDMal]=retifica(HDMal);
%*************************************
%*    Suavização - Low Pass Filter     *
%*************************************
ordem=4;cutOff=12;
 [lDMal]=LPassF(rDMal,cutOff,ordem,SR);
```

```
DadosRaw=lDMal;
DadosEC=DadosRaw(:,1);
%***************************************
%*             Normalização           *
%***************************************
DadosEC=(DadosEC./MaximosLUIS(:,2));
% ********************************************%
%*             Valor Médio (%)            *%
%********************************************%
%%%%GD%%%%
for i=1:3
VAMGD(1,i)=mean(DadosGD(viragem(1,i):viragem(1,i+1)));
end
VAMPGD=VAMGD(1,1);
VAMDSGD=VAMGD(1,2);
VAMFTGD=VAMGD(1,3);
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
% ************************     Pico Máximo (%)      *****************
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
 [onset offset]=onoffset(DadosGD,minLgh,DadosRaw,1);
figure;plot(DadosGD);
vline(offset,'r');
vline(onset,'g');
vline(viragem,'b--');
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%************************
%*    Fim da Rotina     *
%************************
```

Rotina de Onset e Offset:

```
function[liga desliga]=on_set(data,lgh,data2,n)
%-----------------------------------------------------%
%      Treshold for determination of EMG onset         %
%-----------------------------------------------------%
%   This part of the algorithm was created based on     %
%   script written by Rex H. Wu                        %
%-----------------------------------------------------%
window=50;        %
%-----------------------------------------------------%
%             Muscle Onset Calculation (1)             %
%-----------------------------------------------------%
for i=1:14
PMAX(i)=find(data2(:,i)==max(data2(:,i)));
end
treshold1=data(PMAX(n)-50);
treshold2=data(PMAX(n)+50);
i=1;
for h = 1:lgh-window
if data(h) & data(h:h+window) >= treshold1
inivalue(i)=h;
```

```
i=i+1;
end
end
if i==1
onset=1;
else
onset=inivalue(1) ;
end
liga(1)=onset;
%-------------------------------------------------------%
%             Muscle Offset Calculation (1)             %
%-------------------------------------------------------%
i=1;
for h = liga(1):lgh-window
if data(h) & data(h:h+window) <= treshold2
inivalue(i)=h;
i=i+1;
end
end
if i==1
offset=1;
else
offset=inivalue(1);
end
desliga(1)=offset;
int=abs(liga(1)-desliga(1));
if onset==1|offset==1
pmax(1)=0;
local_pmax(1)=0;
end
 [valor local]=max(data(liga(1):desliga(1)));
%------------------------%
%     Fim da Rotina      %
%------------------------%
```

ANEXO 2

(Poster – Estudo III)

Electromyographic analysis of trunk muscles during the golf swing performed with two different clubs

Marta, S., Silva, L., Correia, N., Vaz, J., Bruno, P., Pezarat-Correia, P.

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Technical University of Lisbon, Portugal

Purpose The main objective of this study was to compare the EMG patterns of trunk muscles during the different phases of the golf swing performed with two different clubs: a pitching wedge and a 4-iron.

Methods Ten male golfers (handicap range 5-20) performed, in a random sequence, five swing shots with the pitching wedge and five swings with the 4-iron. Surface electromyography (sEMG) was recorded from trunk muscles of both sides: rectus abdominis (RA), external oblique (EO), internal oblique (IO), erector spinae (ES) and gluteus maximus (GM). The EMG signals were normalized using the EMG of the maximal voluntary contraction (MVC) as reference. For delimitation of golf swing phases the swing was filmed with four high speed video cameras (3 x 100 Hz and 1 x 1000 Hz). The average amplitude of the EMG signal during each phase of the golf swing was determined. For EMG data processing and analysis, automatic routines using the MATLAB® software were developed after a visual inspection of raw EMG signals was done by experienced researchers. Descriptive statistics were reported as mean ± SD. Data were tested for normality with the Shapiro-Wilk test. Paired t-tests were performed to assess differences between club types (pitch wedge and 4-iron). The significance level was set at 5%.

Results In most of the cases and phases trunk muscles showed higher mean values of EMG activation when the swing was performed with the 4-iron club. Nevertheless, significant statistical differences were found only in some cases. This is probably due to the high degree of variability between subjects.

In the backswing phase significant differences (p=.026) where only found on the left IO despite the slight increase (1% MVC) in the level of activation when the swing was performed with the 4-iron. The right IO (pitch – 35%; 4-iron – 38%), the left EO muscles (pitch – 27%; 4-iron – 33%) and the right EO (pitch – 27%; 4-iron – 31%) were the muscles that presented higher level of EMG activity during this phase.

During Forward Swing phase, significant differences between clubs were found, with higher levels of activity with the 4-iron club, for the left RA (p=.029) and right IO (p=.014) representing differences of 2 and 3% MVC, respectively. The left IO (pitch – 80%; 4-iron – 84%), the right EO (pitch – 55%; 4-iron – 63%) and the right GM (pitch – 62%; 4-iron – 72%) were the muscles that demonstrated greater activity during this swing phase.

Through Acceleration phase no significant differences between clubs were found for any studied muscle during the Acceleration phase. Despite that the left (pitch – 51%; 4-iron – 55%) and right IO (pitch – 48%; 4-iron – 54%), the right EO (pitch – 40%; 4-iron – 58%) and the left GM (pitch – 52%; 4-iron – 67%) were the most active muscles during this phase.

In the course of Early Follow-Through phase the right ES was the only muscle that showed significant differences (p=.032) between clubs, with an increase of 3% MVC when the swing was performed with the 4-iron club. The most active muscles during this phase were the left IO (pitch – 46%; 4-iron – 51%), right IO (pitch – 43%; 4-iron – 46%), the right EO (pitch – 38%; 4-iron – 47%) and the left EO (pitch - 26%; 4-iron – 43%).

Throughout Late Follow-Through phase the IO showed significant differences between the two types of club in both sides, left (p=.003) and right (p=.02), with increases of 11% and 3% MVC, respectively, when the swing was performed with the 4-iron club. The most active muscle during this phase was the left IO (pitch – 56%; 4-iron – 67%). Significant increase was also observed in the left EO (p=.04, 5% MVC) and in the left RA (p=.009, 1% MVC).

Conclusions As a general tendency, trunk muscles showed higher mean values of EMG activation when the swing was performed with the 4-iron club. Nevertheless, no significant statistical differences were found between clubs.

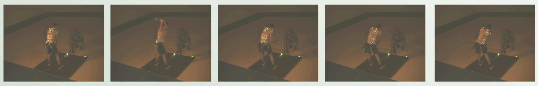

Figure 1 Swing phases.

(BS – backswing; FW – forward swing; AC – acceleration; EFT – early follow-through; and LFT – late follow-through)

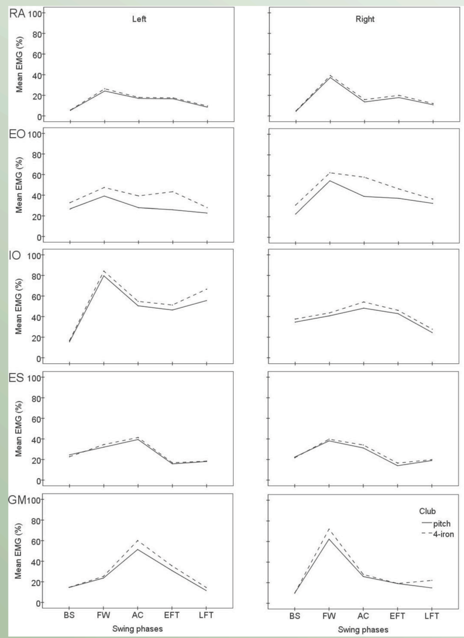

Figure 2 Average amplitude of the EMG signal on left and right sides for the rectus abdominis (RA), external abdominal oblique (EO), internal abdominal oblique (IO), erector spinae (ES) and gluteus maximus (GM) muscles during golf swing phases (BS – backswing; FW – forward swing; AC – acceleration; EFT – early follow-through; and LFT – late follow-through). EMG are expressed in percentage value of the EMG during MVC.

TABLE 1 sEMG (%MVC) by muscle laterality and by club on each swing phase (* p < 0.05, ** p < 0.01)

mean ± SD		swing phases									
		Backswing		Forward Swing		Acceleration		Early Follow-Through		Late Follow-Through	
muscles	side	pitch	4-iron	pitch	4-iron	pitch	4-iron	pitch	4-iron	pitch	4-iron
Rectus Abdominis	left	5.4±2.9	5.7±2.8	24.2±16.2	26.4±16.0*	17.0±11.8	18.0±11.2	16.6±10.1	17.6±7.0	8.5±4.5	9.6±4.9**
	right	4.6±2.1	5.0±2.1	37.3±26.5	39.2±24.1	13.6±7.6	15.9±6.8	17.8±9.4	20.0±10.2	10.8±6.7	12.0±6.1
External Oblique	left	26.7±17.8	32.7±18.6	39.2±19.7	47.5±21.5	27.9±18.9	39.3±37.0	26.0±15.2	43.4±49.1	22.8±10.4	28.0±14.0*
	right	22.6±15.9	31.2±22.5	54.8±23.8	62.6±22.2	39.6±20.0	58.3±31.7	37.8±16.7	47.0±17.0	32.9±16.7	37.1±18.0
Internal Oblique	left	15.6±11.8	16.7±12.1*	79.7±28.4	84.3±21.2	50.5±37.0	54.8±33.3	46.4±26.2	51.3±31.6	55.7±17.9	66.7±24.5**
	right	34.7±21.9	37.7±20.2	40.8±16.8	43.6±16.2*	48.2±20.9	54.3±13.5	42.9±22.7	46.2±17.8	24.5±9.6	27.8±10.6*
Erector Spinae	left	24.6±17.1	22.7±12.9	32.0±17.5	34.6±19.2	39.5±15.6	41.4±16.8	15.8±8.9	16.7±10.6	18.1±9.9	18.4±11.7
	right	22.4±9.8	21.7±9.4	38.2±13.7	39.8±15.9	31.2±19.7	34.1±19.7	14.0±6.0	16.6±7.7*	19.0±12.1	19.9±14.1
Gluteus Maximus	left	14.6±5.9	14.7±4.8	23.7±12.6	25.3±12.6	51.5±24.0	66.5±29.3	31.0±17.1	35.6±24.3	11.5±6.1	14.5±10.0
	right	9.9±5.8	10.0±4.7	62.3±32.3	72.1±38.4	26.0±20.9	28.0±20.2	19.2±15.1	19.3±14.7	15.0±8.9	22.2±18.6

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